HARVARD ENGINEERING SCHOOL

THE

'OTTO' CYCLE GAS ENGINE

A PRACTICAL TREATISE

ON

THE 'OTTO' CYCLE GAS ENGINE

BY WILLIAM NORRIS, M.I.MECH.E.

WITH 207 ILLUSTRATIONS

LONGMANS, GREEN, AND CO.
LONDON, NEW YORK, AND BOMBAY
1896

Engineering appropriation.

PREFACE

THIS work is intended to furnish engineers, draughtsmen, and students with practical data, based as far as possible on the results obtained after years of experience, by the leading makers of the gas engines which work on the common and well-known four-stroke cycle of Beau de Rochas and Otto.

Whether as an additional help in the study of the subject, from the mechanical standpoint, or as an aid to design in the drawing office, where it may find a welcome place as a companion, it is hoped the book will be found of use, and supply a much-felt want.

With this end in view, the author has spared no pains in seeking the most reliable and up-to-date information. Only actual modern gas engines are considered. The various parts of the mechanism of gas engines, self-starters, and other accessories are illustrated and described in detail. The general arrangement, working, and testing of gas engines are dealt with; and the observations, calculations, and results of some careful and elaborate tests are recorded.

I beg to acknowledge my indebtedness to the various

manufacturing firms whose engines are herein described, and who, without exception, have placed the fullest information at my disposal. For valuable assistance in the compilation of the work, and in correcting proofs, I have to thank Professor William Robinson and Mr. David Fergusson.

WILLIAM NORRIS.

Lincoln: *July* 1895.

CONTENTS

PRACTICAL TREATISE

ON THE

'OTTO' CYCLE GAS ENGINE

CHAPTER I

INTRODUCTORY

THE recent development in the use of the 'Otto' cycle gas engine is very striking; more than 700,000 actual horse-power being in use in Great Britain at the present time, including sizes ranging from $\frac{1}{4}$ horse-power to 400 horse-power.

During the early stages of its use, there was a common opinion—held, too, by many engineers who believed in its future—that the gas engine was only suitable for small powers; but single-acting engines, with one cylinder developing 200 effective horse-power, and with two cylinders developing 400 effective horse-power, are now made by many firms, and, whilst not yet in common use, are beyond the experimental stage, and fulfilling all requirements. There cannot be a doubt that the near future will see many manufacturers turning their attention to the larger powers in gas engines.

The credit of establishing them on a sound mechanical basis is justly awarded to Messrs. Crossley Brothers, who from the first had great faith in their future as prime movers, or they would not have undertaken the manufacture of the 1866 free-piston type, which now appears so crude when compared with the celebrated 1876 pattern. If Messrs. Crossley Brothers thought it would one day become the serious rival it has proved

to be to the steam engine, they must have stood almost alone, and can look with pride at the successful results of their pioneer work.

To these pioneers the difficulties must have been very great, inasmuch as they were dealing with a new motor different in principle from the steam engine, and whose working agent was a mixture of gas and air instead of steam. The heat of the steam transformed into useful effort through a process of expansion in the steam engine cylinder needed a separate furnace to generate it, whereas the gas engine dispensed with this outside source of heat, and by burning a mixture of gas and air, generated the heat within itself, and transformed it from the burning and expanding mixture directly into useful energy. Hence the gas engine is an internal combustion engine.

Compared with former experience, gas engine builders had to become accustomed to exceedingly high temperatures, and design and work accordingly. Fortunately the power of certain mineral oils to withstand excessive heat, gets over the difficulty of cylinder lubrication. One point, however, to this day is not satisfactorily solved, viz. :—the manner or method of packing glands for piston rods, to allow the use of a double-acting engine.

This system of transferring the furnace, wherein the heat energy is primarily developed, into the cylinder itself, and there utilising directly the benefits of combustion, is undoubtedly the greatest step of the present half-century in the direction of high economy and efficiency.

The theory of the gas engine has been discussed and rediscussed through a long series of years, and there are even now those who hold views far from consistent with actual facts. Therefore it is advisable that a little should be said now concerning the practical aspect of gas motors in their modern presentment. The advantages of compressing the gas and air before firing were first pointed out about 1860 by Beau de Rochas, who indicated the process of carrying out the four operations—charging, compressing, firing, and exhaust with one piston.

This cycle was realised in 1876 by the Otto 'Silent' gas engine.

It is generally accepted that the modern gas engine, as we have it at present, has been developed by experiment, and so far most engineers, after lamentable errors and waste of time, have reluctantly adopted the Beau de Rochas cycle, as being the simplest system on which an engine can be constructed that will give satisfactory results.

It is not in the scope of this treatise to deal with any other cycle, but it may safely be taken that engines which give an impulse every revolution when working at full power will ultimately take the place of the simple form of 'Four' cycle engine.

CHAPTER II

GENERAL DESCRIPTION OF 'OTTO' CYCLE GAS ENGINE

THE present-day form of the commercial gas engine has a single cylinder, and gives an impulse every two revolutions when working at full power, and closely resembles a single-acting steam engine, with the working parts of excessive strength. The cylinder is open-ended, and has a trunk piston having sufficient bearing surface to dispense with the use of cross-head slides, the connecting rod joining directly the piston and the crank. The crank shaft is heavy and flywheels large, as considerable energy has to be stored to take the piston through the negative parts of the cycle (see fig. 1). The cylinder is considerably longer than the piston stroke, leaving a space at the back end, into which the piston does not enter, called the combustion chamber. Below the centre line of the engine is placed a shaft, rotating at half the speed of the crank shaft, from which it receives its motion by worm gearing, actuating at suitable times the air, gas, exhaust, timing valve, governor, and cylinder lubricator. The cylinder serves alternately the purpose of motor and pump, as during the forward stroke of the piston the air and gas valves are opened by means of cams and levers, and the gas and air enters from about the beginning to the end of the stroke, the return stroke being utilised in compressing the mixture into the compression space; and when the piston is full in the pressure has risen to

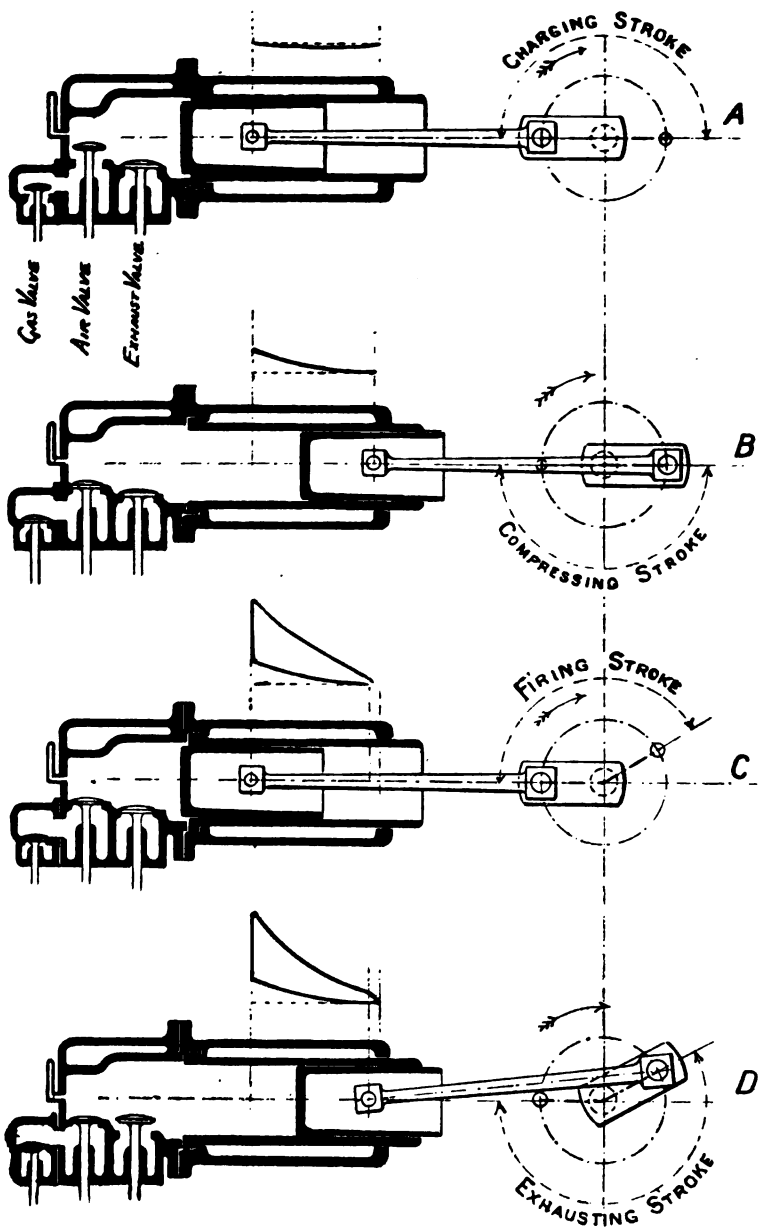

CHARGING STROKE
A
GAS VALVE
AIR VALVE
EXHAUST VALVE
B
COMPRESSING STROKE
FIRING STROKE
C
D
EXHAUSTING STROKE

FIG. 1

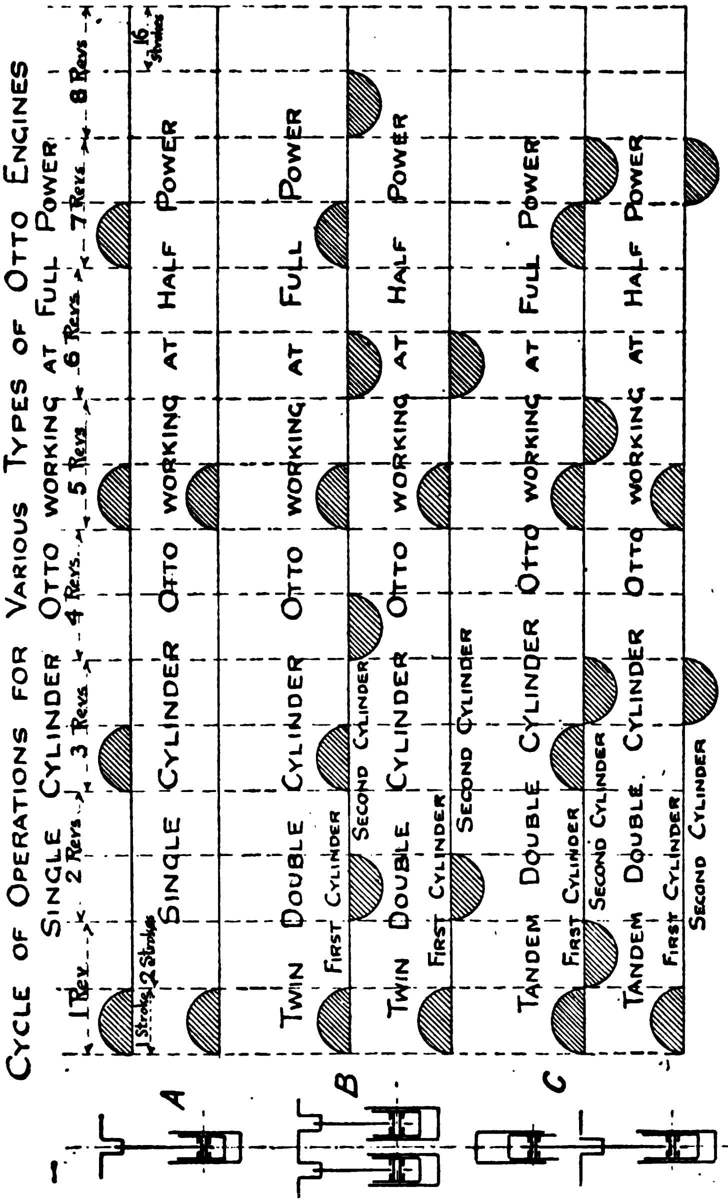

Cycle of Operations for Various Types of Otto Engines
Single Cylinder Otto working at Full Power
1 Rev
2 Revs
3 Revs
4 Revs
5 Revs
6 Revs
7 Revs
8 Revs
1 Stroke
2 Strokes
16 Strokes
Single Cylinder Otto working at Half Power
Twin Double Cylinder Otto working at Full Power
First Cylinder
Second Cylinder
Twin Double Cylinder Otto working at Half Power
First Cylinder
Second Cylinder
Tandem Double Cylinder Otto working at Full Power
First Cylinder
Second Cylinder
Tandem Double Cylinder Otto working at Half Power
First Cylinder
Second Cylinder
A
B
C

FIG. 2

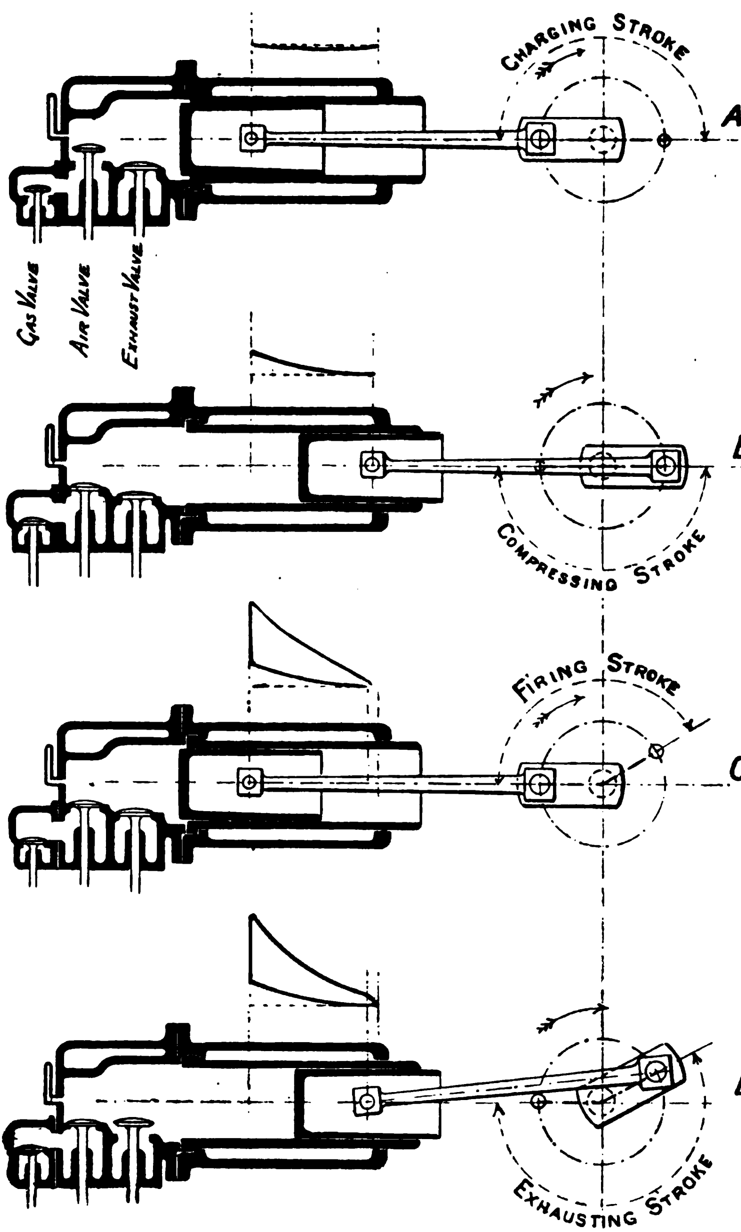

CHARGING STROKE
A
GAS VALVE
AIR VALVE
EXHAUST VALVE
B
COMPRESSING STROKE
FIRING STROKE
C
D
EXHAUSTING STROKE

FIG. 1

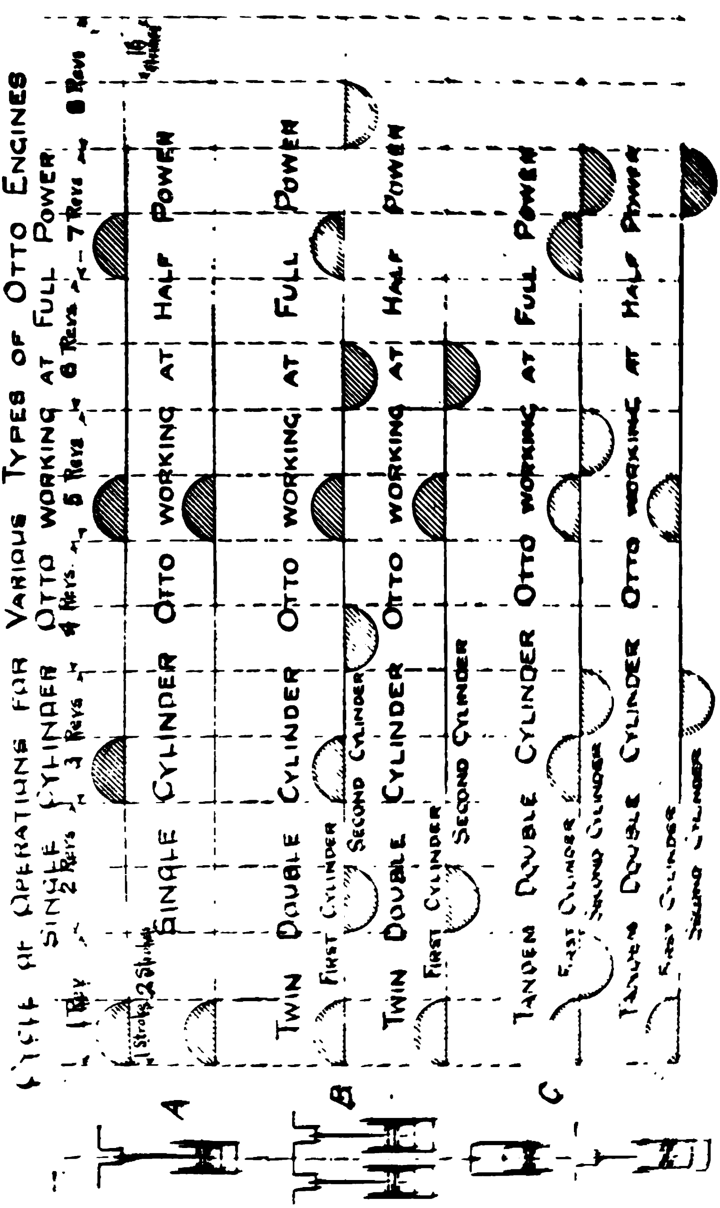

Cycle of Operations for Various Types of Otto Engines
Single Cylinder Otto working at Full Power
1 Rev
2 Revs
3 Revs
4 Revs
5 Revs
6 Revs
7 Revs
8 Revs
1 Stroke
2 Strokes
16 Strokes
Single Cylinder Otto working at Half Power
Twin Double Cylinder Otto working at Full Power
First Cylinder
Second Cylinder
Twin Double Cylinder Otto working at Half Power
First Cylinder
Second Cylinder
Tandem Double Cylinder Otto working at Full Power
First Cylinder
Second Cylinder
Tandem Double Cylinder Otto working at Half Power
First Cylinder
Second Cylinder
A
B
C

Fig. 1

the predetermined amount relative to the capacity of the space to the cylinder volume. Meanwhile the timing valve has opened communication with an incandescent tube, and the compressed charge igniting, the pressure rises so rapidly that the maximum is reached before the piston has moved appreciably on its second forward stroke. The whole stroke is used for expansion as the piston is under its highest pressure at the commencement. This is called the power stroke; near the end of it the exhaust valve opens, and the return stroke is occupied in driving out the burnt gases, except that portion remaining in the compression space untraversed by the piston. These operations form a complete cycle, and the piston is again in the position to take in the charge required for the next impulse.

The regulation of the speed is controlled by a governor arranged to throttle the gas or effect a complete cut-out.

Although the idle strokes of the 'Otto' cycle are far from theoretically correct, experience has proved that the use of one cylinder and piston, serving alternately the purpose of motor and pump, has undoubted compensating advantages.

This cycle of operations, both for single cylinder and multi-cylinder engines, can be better seen by reference to figs. 1, 2, 3, and 4.

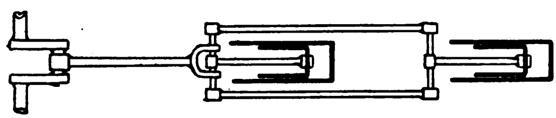


FIG. 3

Fig. 1, A, represents the conditions at the commencement of the charging stroke of a single cylinder engine. The air and gas valves are shown open to allow the free inlet and admixture

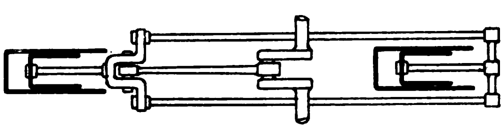


FIG. 4

of air and gas whilst the piston travels to the end of its outward journey. B shows the valves closed and piston ready to

perform its second operation—viz. that of compressing the charge already drawn in. C represents the power stroke; D the exhausting stroke, showing the piston ready to expel the products of combustion.

Fig. 2 shows in another form the cycle of operations of various types of engines, and the cycles of figs. 3 and 4 correspond to section B of fig. 2.

CHAPTER III

DEFINITION OF HORSE-POWERS

AT present much confusion is caused by the way in which various makers give the power of their engines, Nominal, Indicated, Brake, Effective, and Actual horse-power being often used to describe the same engine.

The term 'nominal' is an arbitrary term, without a satisfactory basis to justify its use, as it is not common to any two makers, and even with the same makers the given indicated horse-power has varied from twice to four times the given nominal power.

Indicated horse-power until quite recently was based upon a good-sized diagram and the maximum number of ignitions obtainable—viz. half the number of revolutions of the crank shaft—and was supposed to represent the maximum indicated horse-power; whereas, as a matter of fact, the maximum working load would be at least 20 per cent. less.

Brake, effective, or actual horse-power are only different expressions for the same thing—viz. the net available horse-power that can be taken from the engine. These latter, it will be seen, are the only definitions common to all engines, and the standard by which they should be judged for continuous runs of at least six hours.

The expressions used throughout this Treatise will be:

Nominal horse-power, NOM. H.P.

Indicated horse-power, I.H.P.

Brake, effective, or actual horse-power, B.H.P.

Many people have had their faith in the value of gas engines very much shaken because of want of practical advice in laying them down. Experience teaches that in the first place a considerable margin of power must be provided over and above that specified by the makers. Gas engines will not work regularly and satisfactorily over a run of an indefinite length of time with the full specified load, and there is no doubt that the makers are mainly responsible for the disfavour with which they are often viewed, as they repeatedly—no doubt driven to it by competition—recommend engines which will barely do the work required of them. There is a constitutional difference between the systems of obtaining power from a steam and gas engine that places them on an entirely different basis. A steam engine may be worked up to its test load for almost any length of time, but not so a gas engine. What is given off over a few hours' test must not be considered the working power of the engine, and if gas engine makers will only acknowledge this practical fact and fix a ' working load ' for each engine, instead of the maximum B.H.P. or I.H.P. as at present, they will soon rise higher in popular favour.

The author's experience is that with a load two-thirds of that specified by the makers, gas engines work smoothly and well, but with anything over this, trouble is to be expected.

CHAPTER IV

TYPES OF ENGINES BY VARIOUS MAKERS

Crossley Bros. (Limited), Manchester

FIG. 5 is a longitudinal section, fig. 6 a plan, and fig. 7 an external elevation of a 7 H.P. NOM. engine, having a cylinder $8\frac{1}{2}$ inches in diameter, and a stroke of 18 inches, and may be taken as well representing this firm's present practice.

The cylinder A and combustion chamber B are arranged with a continuous water jacket C, and are fitted with a liner D of

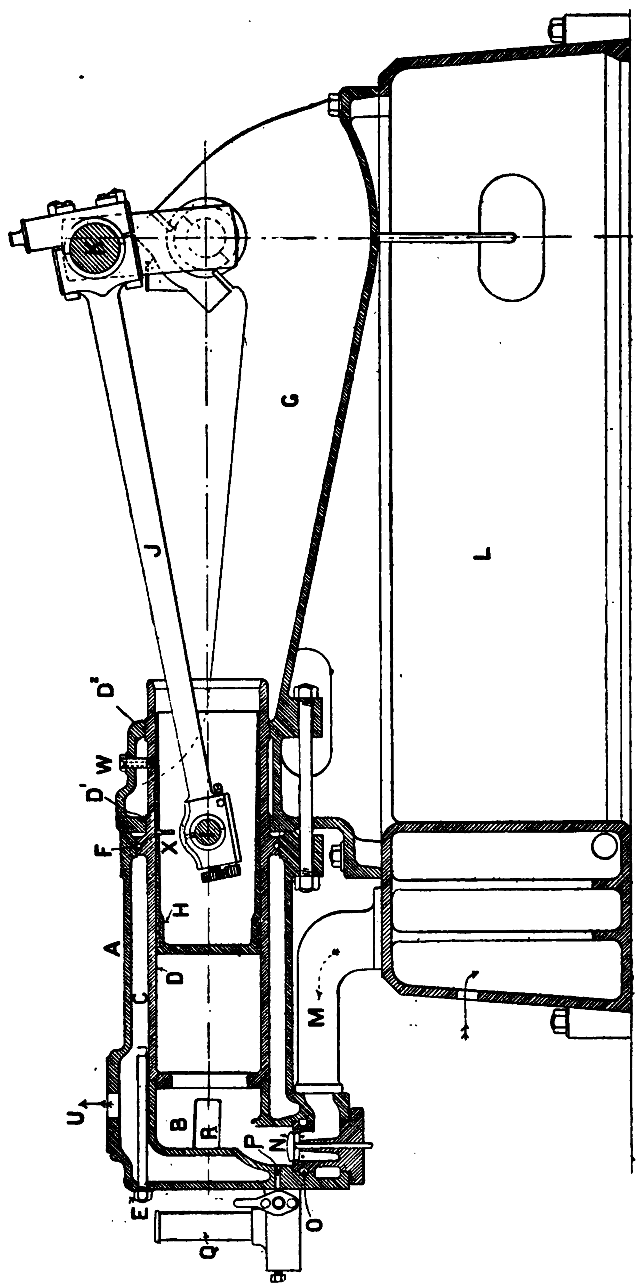


FIG. 5.—7 H.P. NOM. CROSSLEY ENGINE (LONGITUDINAL SECTION)

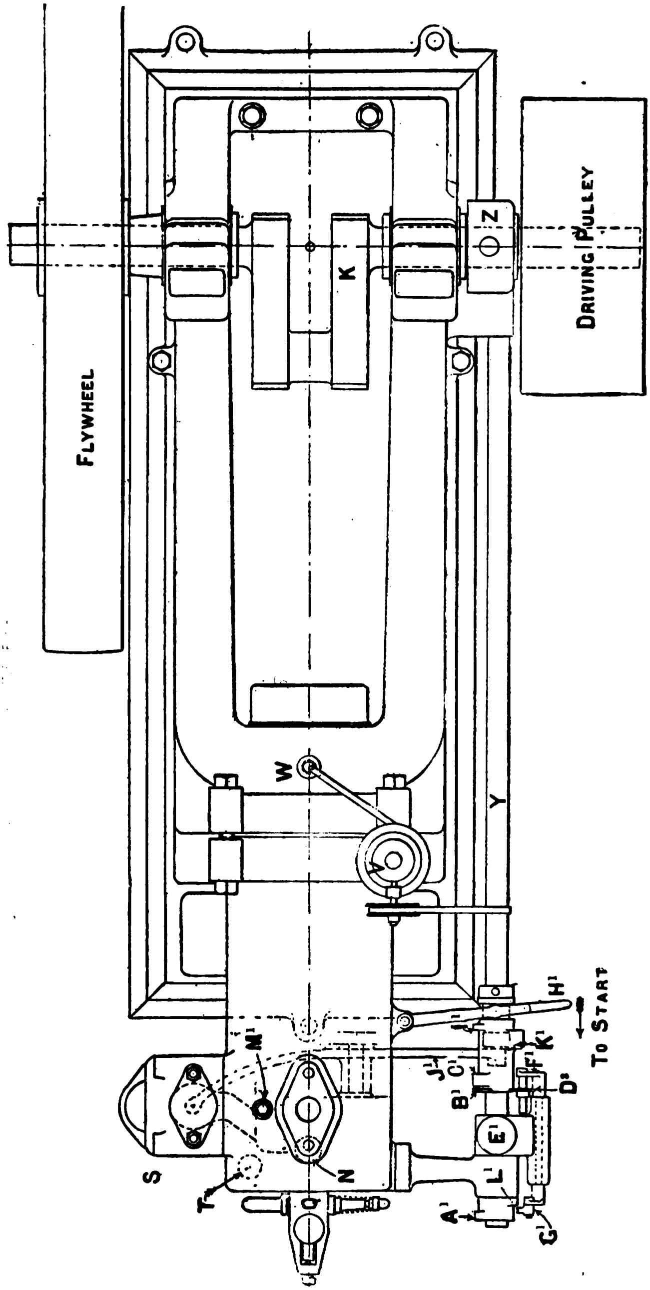


FIG. 6.—7 H.P. NOM. CROSSLEY ENGINE (PLAN)

a special hard cast iron, easily drawn when damage or wear necessitates its removal. This liner is secured to the cylinder by bolts E, fig. 5, drawn through the back end of the compression chamber, and the front end, where it enters the cylinder proper, is fitted with a rolling rubber ring F to allow the liner in expanding or contracting to maintain a water-tight joint. The front end of the liner at D^1 and D^2 is fitted into the bed G, so that in disconnecting the cylinder from the base no water joints are broken.

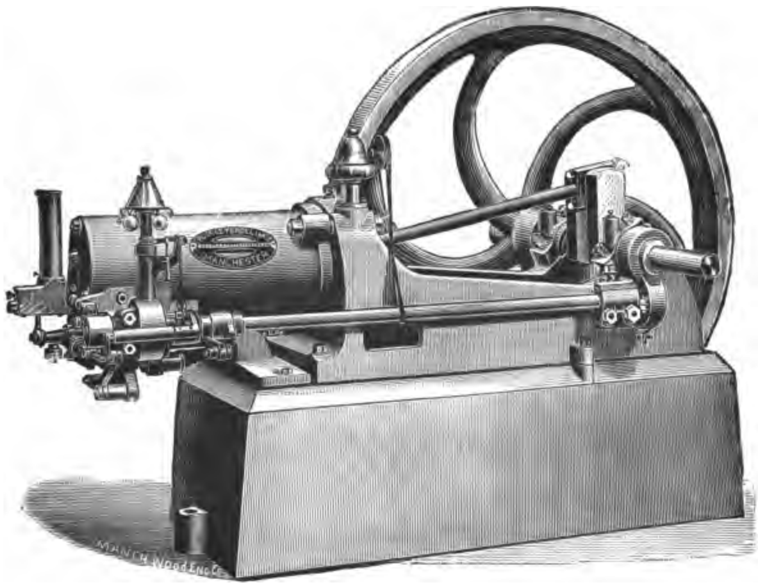


FIG. 7.—7 H.P. NOM. CROSSLEY ENGINE

The piston H is arranged with bosses in the centre through which the pin I is fitted, and by which the connecting rod J is coupled direct to the crank pin K. The base L, to which the bed G is firmly bolted, is provided with an arrangement of baffle plates, to silence the inrush of air through the pipe M, which forms the connection between the base and the box containing the air valve N, arranged below the direct line of fire, with a gas channel O to ensure the gas mingling with the inrushing air. P is the igniting port, in direct communication with the timing valve and hot tube Q. The exhaust port R, fig. 5, is shown

leading to the valve-box S, fig. 6. The cold water is admitted at the extreme bottom end of the combustion chamber at T, and the hot water outlet is arranged at U. V is the cylinder lubricator, from which the oil runs down a small pipe and enters the cylinder at W; it is worked by an endless leather belt from the cross shaft Y, which is driven by the worm wheels at Z.

The cam and lever arrangements are clearly shown. A^1 represents the air cam, B^1 the normal working gas cam, C^1 a gas cam used at starting only, D^3 the gas roller controlled by the governor E^1; F^1 is a cranked rocking shaft, at one end carrying the pin upon which the gas roller works, and at the other transmitting the cam motion to the gas valve through the connecting link G^1. The position of the lever H^1, which has control of the cams B^1, C^1, I^1, and K^1, is the normal position when the engine is running, but at starting it is moved in the direction indicated by the arrow until the cam I^1, which is a relieving cam for the exhaust, acts as well as the ordinary cam K^1 upon the exhausting lever J^1, and the cam C^1 takes the place of the normal gas cam B^1; L^1 is the timing valve cam and M^1 a plug for the indicator.

The weak point in this engine is the position of the exhaust valve box. This being placed at the side and in direct communication with the main water jacket C, whilst the main valve opens to the cylinder, the vibration of the engine and the high temperature of the gases tend to break the joint, as the exhaust pipe is at one end rigid and does not respond to any oscillation set up by the engine.

Fig. 8 is an external elevation of a 30 H.P. NOM. engine capable of indicating 100 H.P. with ordinary gas when running at 160 revolutions per minute, and has a cylinder 17 inches diameter with a stroke of 24 inches.

A girder frame type of engine admits of the strains being taken in a direct line between the centres of the crank shaft and the cylinder, and prevents all possibility of the engine 'panting.' In this engine there are two main girders, one from each bearing to the cylinder, the crank running between them. The combustion chamber is a separate casting bolted to the end of the cylinder, and the liner of the cylinder is held in position by bolts drawn through it. The air and gas valves are on the extreme

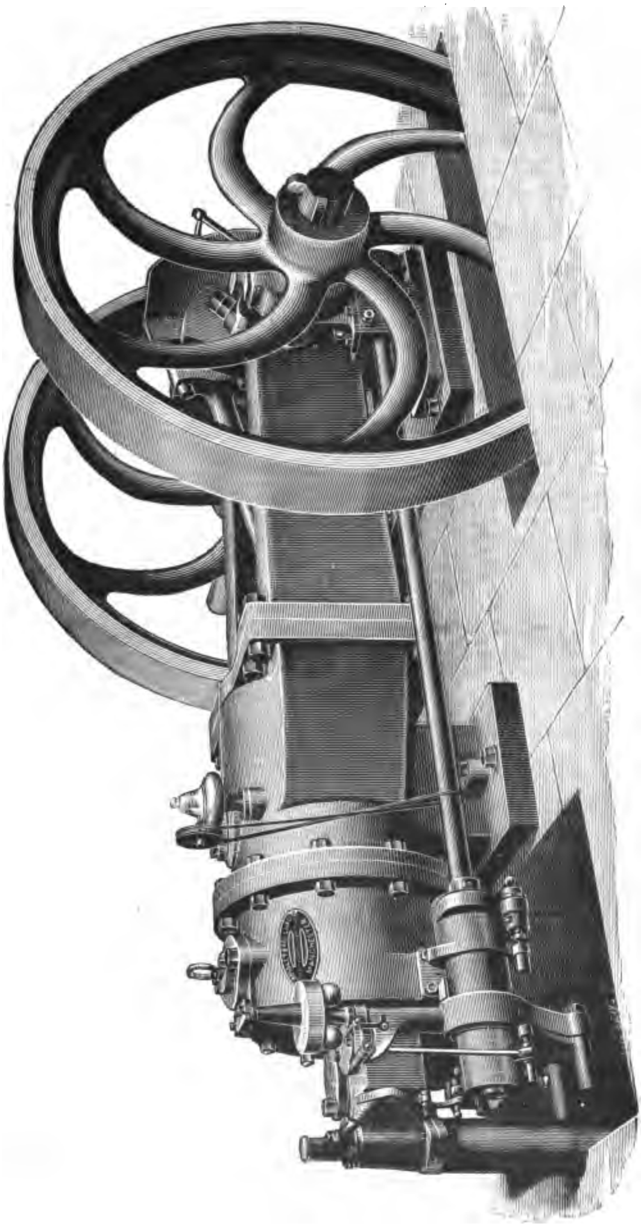


FIG. 8.—30 H.P. NOM. CROSSLEY ENGINE

end of the combustion chamber, the exhaust valve at about its centre, in a direct line of fire. A defect in this engine is the angle and direction at which the main bearings are placed, which throws a great proportion of the force of the explosion on the cap bolts, instead of on the main casting; this is not good practice, especially when we consider that even with producer gas a maximum pressure of 320 lbs. per square inch is reached.

This form of engine was also made in coupled twin form, having four bearings, and on the outside of each outer bearing a heavy flywheel, and with cranks arranged so that one piston was full in when the other was full out, the cycle of operations being the same as shown on fig. 2 at C. But as it was impossible for the middle bearings to wear down at the same rate as the outer ones, because of the weight of the flywheels, and the power transmitted, the crank shaft was found to spring backwards and forwards at each throw of the crank; and unless the middle bearings were carefully and periodically lined to the outer ones, the strain would eventually have become too great and produced disastrous results. This evil has been overcome by the tandem engine, having a cylinder on each side of the crank shaft as shown at fig. 9. This type of engine does not, however, divide the work in the best possible manner, as two impulses follow each other at full power, followed by two idle strokes (see fig. 2, as shown at C). In practice, however, this makes very little difference; the advantage of two cylinders over one is that it reduces each individual impulse. Commercial requirements necessitate that sometimes the governor must cut out impulses, and as this covers a large proportion of the time of working, it is the usual condition. This being so, and taking into account the chapter of accidents which occur with the best of governors, it becomes a matter of very little importance if the impulse next to be cut out immediately follow a previous impulse, or has a single stroke between.

These engines are made in the following sizes: 60 H.P. NOM. indicating 200 H.P., and 80 H.P. NOM. indicating 250 H.P., with ordinary town gas, when running at 160 revolutions per minute. If, however, producer gas is used, the I.H.P. is less by about 15 per cent.

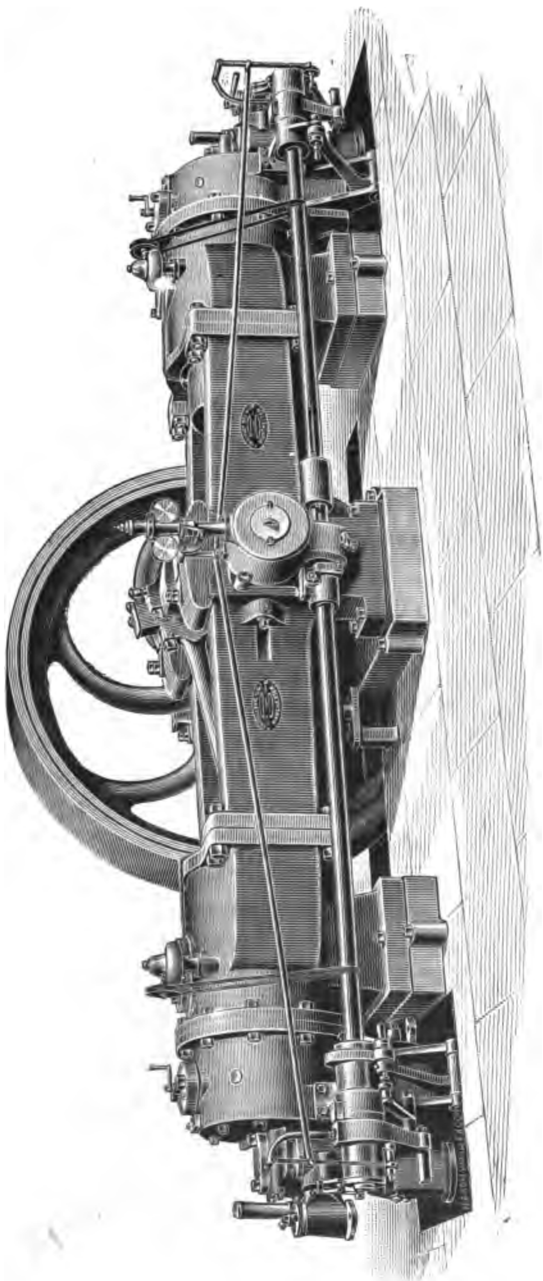


FIG. 9.—60 H.P. NOM. CROSSLEY TANDEM ENGINE

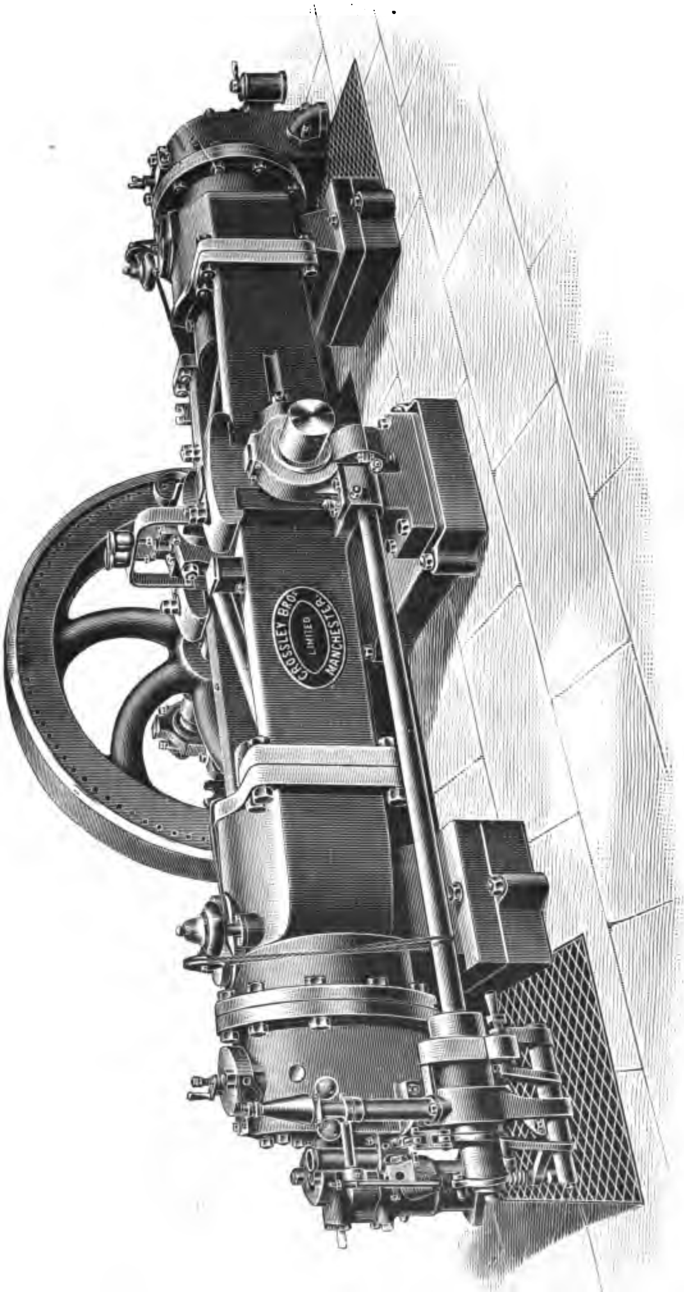


FIG. 10.—60 H.P. NOM. CROSSLEY TANDEM ENGINE

Fig. 10 is an external elevation of their latest design of this size and type of engine. It differs from fig. 9 in that each engine is provided with independent gears, so that either engine can be disconnected. This design enables the makers to dispense with right and left hand combustion chambers, and makes a thoroughly well designed engine.

Fig. 11 is a 25 H.P. NOM. engine, having a cylinder 16 inches diameter and a stroke of 21 inches; it is capable of indicating as a maximum 64 H.P. The arrangement of the valves and gearing is approximately the same as in the girder type engine; but its

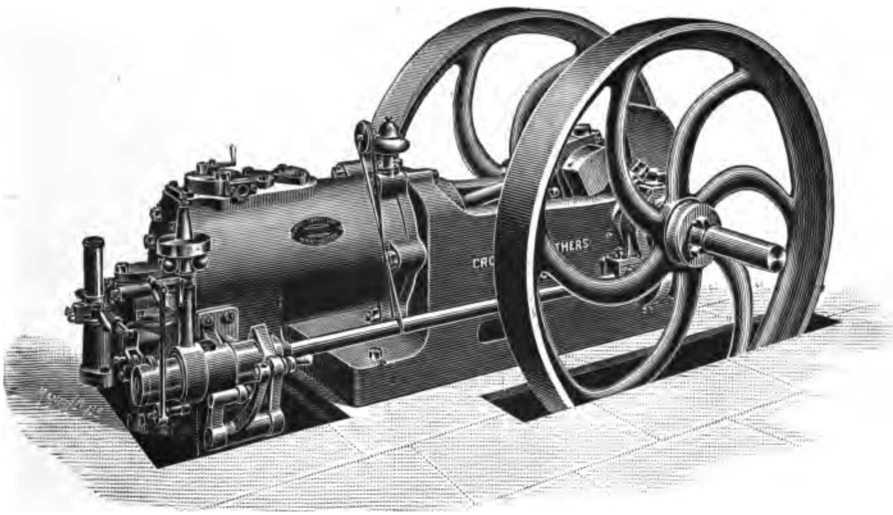


FIG. 11.—25 H.P. NOM. CROSSLEY ENGINE

own distinctive feature is the firm grip it has upon the foundation, whilst the centre line is kept very low. It, however, has the same defect in the angle and direction of its bearings as fig. 8, which neutralizes many of its otherwise valuable points. This design of bed is also used in 40 and 50 H.P. NOM. engines, the cylinders of which and combustion chambers are separate, with the exhaust valve box cast on the side of the latter. One heavy flywheel instead of two lighter ones, as in fig. 11, is used, and an outer bearing arranged to take the weight.

In fig. 12 is shown a typical engine made by this firm for

the special purpose of driving a dynamo direct from the flywheel for electric lighting, for which purpose their practice is to have large diameters in the cylinders, comparatively short strokes, and heavy flywheels running at a very high rate of speed—viz. from 250 to 350 revolutions per minute. The crank shaft is balanced by means of weights placed in the flywheels, so that they move at the same mean velocity as the parts to be balanced, although at considerable distance from the centre line of the cylinder. The gas, air, and timing valves are placed horizontally

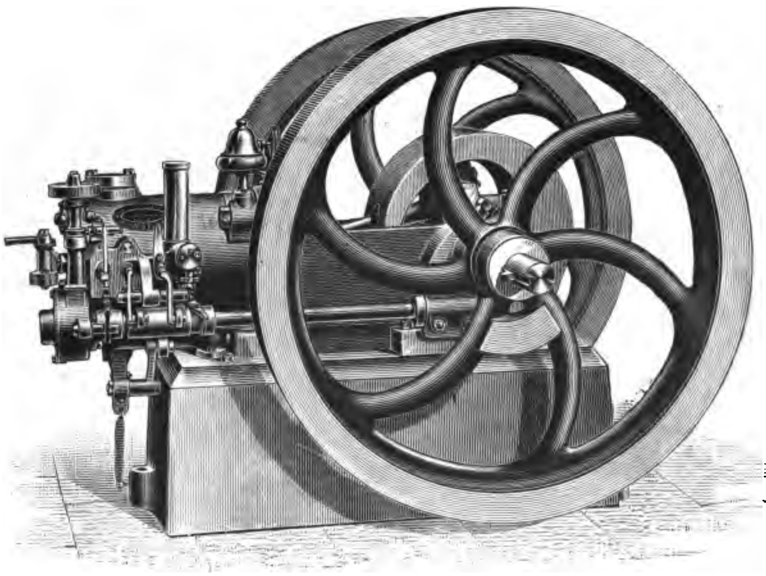


FIG. 12.—CROSSLEY'S HIGH-SPEED ELECTRIC LIGHT ENGINE

on the side of the cylinder, with the exhaust valve vertical. A centrifugal governor is used combined with the pecker action. The same proportions and practice are used in a tandem and quadruple design; the former being, like fig. 10, a combination of a right and left hand engine, having, however, only one flywheel and outer bearing. The quadruple engine giving two impulses per revolution when working at full power is practically a double tandem engine, with one flywheel between the two engines, having discs and overhanging crank pins instead of the ordinary

crank shaft with double jaws, and one governor to control the whole.

It seems more than possible that makers of these excessively high-speed engines will find that much better results can be obtained by using a long stroke, balanced engine, with larger flywheels running at a slower speed.

The misleading term of 'NOMINAL HORSE-POWER' is happily not used in these engines, each size being rated at its effective

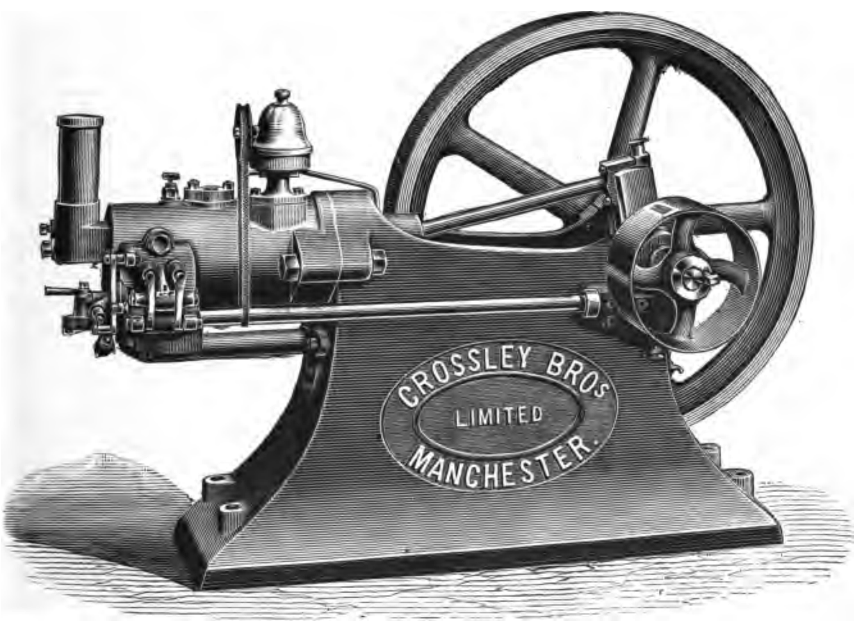


FIG. 13.— $\frac{1}{2}$ H.P. NOM. CROSSLEY ENGINE

power. And it would be well if the same principle were applied to all sizes, and instead of calling—say, fig. 13—$\frac{1}{2}$ H.P. NOM., it were rated as a $2\frac{1}{2}$ B.H.P. This engine contains some of the features of the high-speed type, in that the air and gas valves being placed horizontally in one box are easily disconnected from the engine if necessary, although the horizontal position is not good practice. It is governed by Holt's effective inertia governor, worked by a small crank on the end of the cross

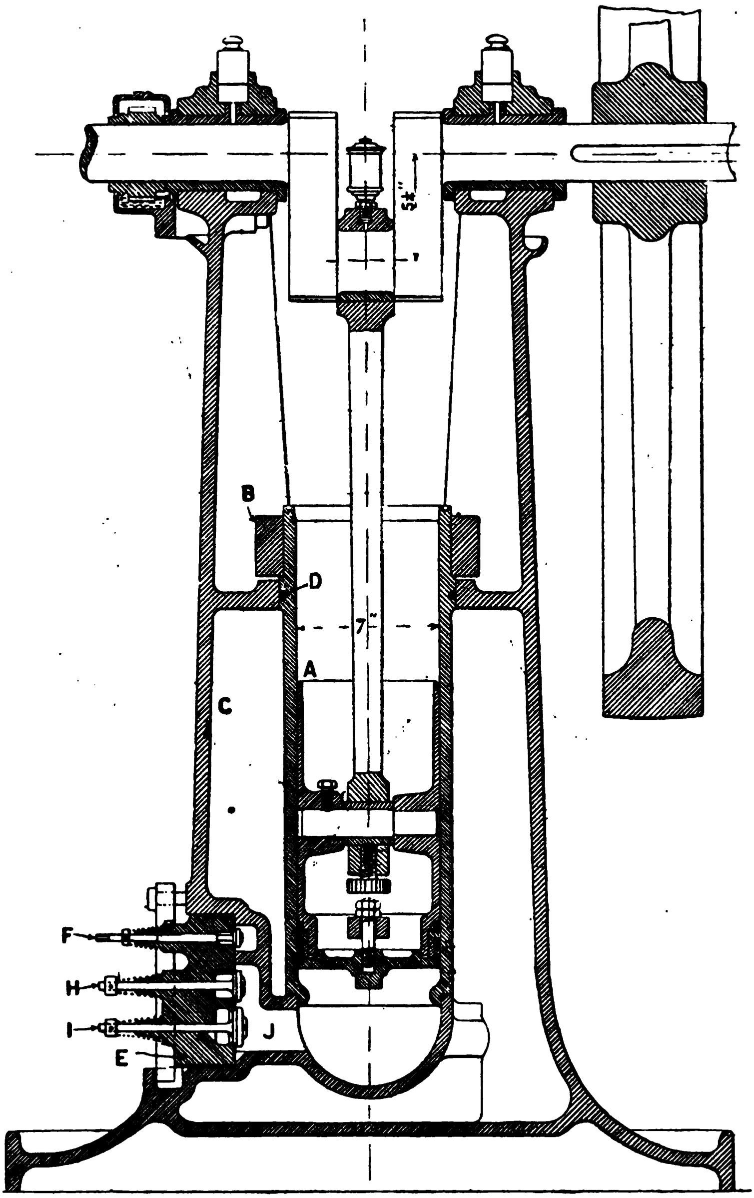


FIG. 14.—3 H.P. NOM. VERTICAL CROSSLEY ENGINE (SECTIONAL ELEVATION)

shaft, and has no timing valve, and, unlike the general practice of this firm, is not provided with a renewable liner to the cylinder.

All the engines previously described have been of the horizontal type, but as there are many positions where, from considerations of room, it would be impossible to fix a horizontal

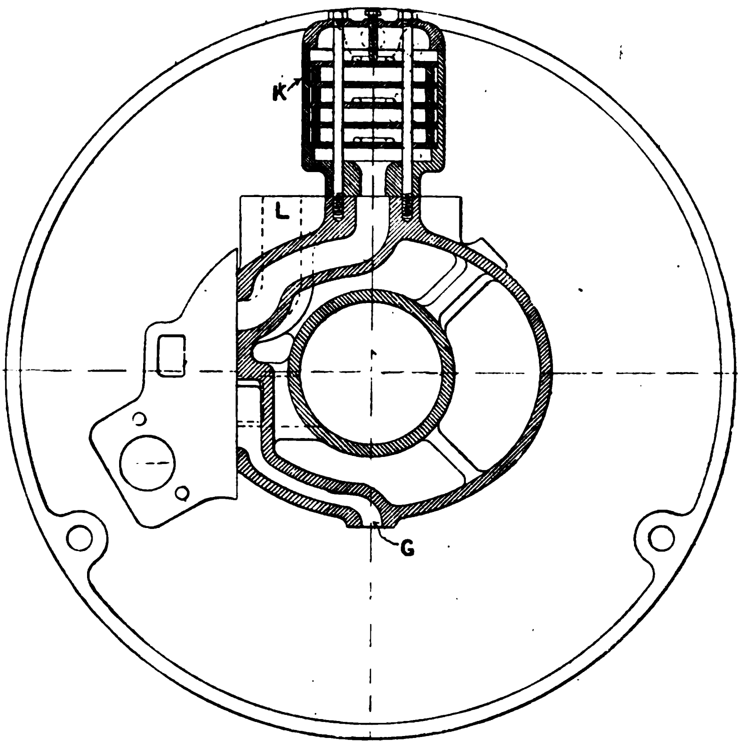


FIG. 15.—3 H.P. NOM. VERTICAL CROSSLEY ENGINE (SECTIONAL PLAN)

engine, it has been found necessary to make a vertical one, and figs. 14, 15, and 16 show in section, plan, and external elevation such an engine of 3 H.P. NOM. The cylinder being 7 inches diameter by 10½ inches stroke, is formed by forcing a liner A, by means of a gland B, into the main casting C, and leaving an annular space between the two to form a water jacket. The

joints are made at the bottom by asbestos to withstand the heat, and at the top by a rolling rubber ring D. In all respects this is an almost ideal engine of a vertical pattern.

FIG. 16.—3 H.P. NOM. VERTICAL CROSSLEY ENGINE

The valve arrangement is simplicity itself. The box E, which is easily disconnected, contains the gas, air, and exhaust valve. The gas valve F is connected by the passage G to the gas cock shown in the elevation. The air valve H and exhaust valve I, whilst having the same passage, J, to the cylinder, have separate passages in the box E. The air is drawn through the silencer K, and the exhaust outlet is shown at L.

The Clerk-Lanchester pressure starter is used by these makers, and fitted to all large-sized engines.

CROSSLEY ENGINES

SINGLE CYLINDER HORIZONTAL ENGINES—1895

Nominal h.p.	Maximum Indicated h.p.	Maximum Actual or Brake h.p.	Over all Dimensions (of Engine only)				Net Weight of Engine		Standard Size of Pulley		Size of Fly-wheels			Speed	Bore of Cylinder	Length of Stroke	Diameter of Crank Shaft
			Length		Breadth				Diam.	Wide	Diameter		Wide				
			ft.	in.	ft.	in.	c.	q.	in.	in.	ft.	in.	in.	Revs.	n	in.	in.
½	2·5	2	5	6	2	5	10	0	10	5	2	11	3½	200	4½	10	1⅝
1	3·8	3	6	3	4	1	18	2	12	6	4	0	4⅞	200	5½	10	—
2	4·75	3·5	7	6	4	0	23	0	17	6	4	6	4¼	200	5¾	12	—
3	6·5	5	7	6	4	0	27	2	20	7	4	8	5¼	200	6¾	12	—
4	9·8	7·8	8	6	4	3	36	0	20	7	5	0	4⅞	200	7	15	—
6	13·	10·5	9	0	5	0	49	1	24	10	5	6	6⅛	190	8	17	—
7	15·6	13	9	11	5	0	54	0	24	10	5	6	6¼	180	8½	18	3¼
9	19·5	16	10	6	5	9	63	2	27	12	5	6	7	180	9½	18	3½
10	21·5	18	10	6	5	9	64	0	30	12	5	6	7	180	—	—	—
12	26·2	22	9	6	7	0	89	0	36	12	5	6	6¼	180	11½	16	4
14	34	29	10	9	7	0	105	0	48	14	5	6	7	170	11½	21	4¼
16	41	35	11	3	7	9	138	0	54	16	5	10	8	160	13	21	—
20	49		12	0	8	2	150	0	54	18	5	10	9	160	14	21	5½
25	64	54	13	0	8	9	144	0	—	—	7	1	10¼	160	16	21	6¼
30	90	79	14	3	9	9	210	0	—	—	7	2¾	10¼	160	17	24	–
40	110	97	14	6	10	0	220	0	—	—	7	2¾	10¼	160	—	—	–

TANDEM HORIZONTAL ENGINES

Nominal h.p.	Maximum Indicated h.p.	Maximum Actual or Brake h.p.	Over all Dimensions (of Engine only)		Net Weight of Engine	Standard Size of Pulley		Size of Fly-wheels		Speed	Bore of Cylinder	Length of Stroke	Diameter of Crank Shaft
			Length ft. in.	Breadth ft. in.		Diam. in.	Wide in.	Diameter ft. in.	Wide in.	Revs.	in.	in.	in
60	**180**	**158**	21 0	9 6	—	—	—	7 6	19	160	17	24	—
80	**220**	**194**	21 6	10 0	—	—	—	7 6	19	160	—	—	—

SINGLE CYLINDER VERTICAL ENGINES

Nominal h.p.	Maximum Indicated h.p.	Maximum Actual or Brake h.p.	Over all Dimensions (of Engine only)		Net Weight of Engine	Standard Size of Pulley		Size of Fly-wheels		Speed	Bore of Cylinder	Length of Stroke	Diameter of Crank Shaft
			Height ft. in.	Breadth ft. in.	c. q.	Diam. in.	Wide in.	Diameter ft. in.	Wide in.	Revs.	in.	in.	in.
2 m.p.	**¾**	**·4**	3 2	2 3	6 0	5	4	2 2½	3⅝	250 to 300	—	—	..
5 m.p.	**1·3**	**·9**	4 8	3 sq.	9 3	10	5	2 11	3½	200	—	—	—
½ h.p.	**2**	**1·25**	4 8	3 0	11 2	10	5	3 0	3¾	200	—	—	—
1½ h.p	**3**	**2**	5 10	4 0	17 0	17	6	4 0	4¾	200	5¾	9	2¼
3 h.p..	**6**	**5**	6 9	4 8	24 0	20	7	4 7½	4¾	200	7	10½	2¾

HIGH-SPEED ELECTRIC LIGHT ENGINES (SINGLE CYLINDER)

Type	Maximum Actual or Brake h.p.	Over all Dimensions (of Engine only)		Net Weight of Engine	Size of Fly-wheels		Speed	Bore of Cylinder	Length of Stroke	Diameter of Crank Shaft
		Length ft. in.	Breadth ft. in.	c. q.	Diameter ft. in.	Wide in.	Revs.	in.	in.	in.
Horizontal . .	**2·5**	5 6	2 5	11 0	3 6	2⅞	300	4½	10	1⅝
" . .	**5·5**	6 9	5 0	46 0	4 7½	6	250	—	—	—
" . .	**8·5**	6 9	5 0	63 0	4 7½	7½	250	8½	12	3¼
" . .	**14**	7 10	6 3	80 0	5 2½	8½	250	—	—	—
		Height								
Vertical . . .	**3**	6 0	4 1	30 0	4 1	6½	280	5¾	9	2¼
" . . .	**5**	6 7	4 7½	40 0	4 7½	6	250	7	10½	2¾

CROSSLEY ENGINES—1879

Nominal h.p.	Indicated h.p.	Speed
		Revs.
½	1·1	160
1	2·26	160
2	3·96	160
3½	5·9	160
6	11·57	160
8	14·7	160
12	23·1	160
16	36	160

It is interesting to note that the 1879 catalogue from which the foregoing table is taken contains the following: 'Tenders for larger sizes and for "compound engines" on application.'

Robey & Co. (Limited), Lincoln

On the expiration of the 'Otto' patent Messrs. Robey & Co. decided to manufacture gas engines, using the 'Otto' cycle, with various structural modifications introduced by the author in 1890.

Figs. 17, 18, and 19 being a section, plan, and external elevation of an engine capable of developing 24 B.H.P., represent the characteristic features of the valve arrangements of all sizes. The cylinder of this engine is 11 inches diameter and the stroke 18 inches. It will be seen that the cylinder A and bed are in one casting, the water jacket B coming well up to the end of the liner C, which is forced in from the back, and made tight by metallic joints only, and kept in position by the combustion chamber F, which is bolted to the end of the cylinder, having a projection fitting into a recess formed by making the liner a little shorter than the cylinder. The whole of the combustion chamber is water-jacketed, G, although not in communication with the main jacket B, and has a separate inlet H and outlet I; D and E being the supply and outlet to the cylinder jacket, the bridge pieces connecting them with the main supply and outlet pipes. By arranging the areas of the relative openings proportionate to the needs of the combustion chamber and main jacket, a most efficient circulation is obtained. The air valve J and exhaust valve K being in the direct line of the impulse greatly facilitate both the inlet of the charge and expulsion of the products of the combustion; and as the gas entering at L through the channel M meets the inrushing air drawn from the air-silencing chamber O (placed inside the base N) through the pipe P, a pure mixture is ensured at the nearest point of ignition—viz. the igniting port Q, which being a very short one and on the direct line of engine, ensures a very reliable ignition without a timing valve.

R is the gas inlet from the main gas cock L, used for the

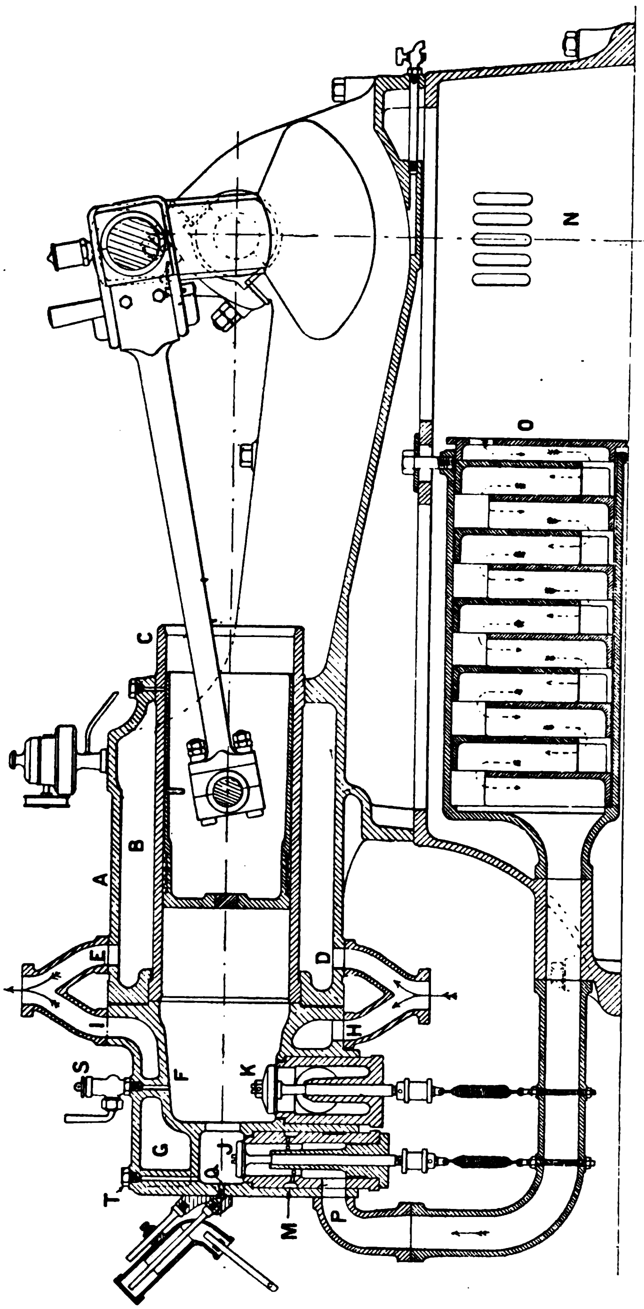
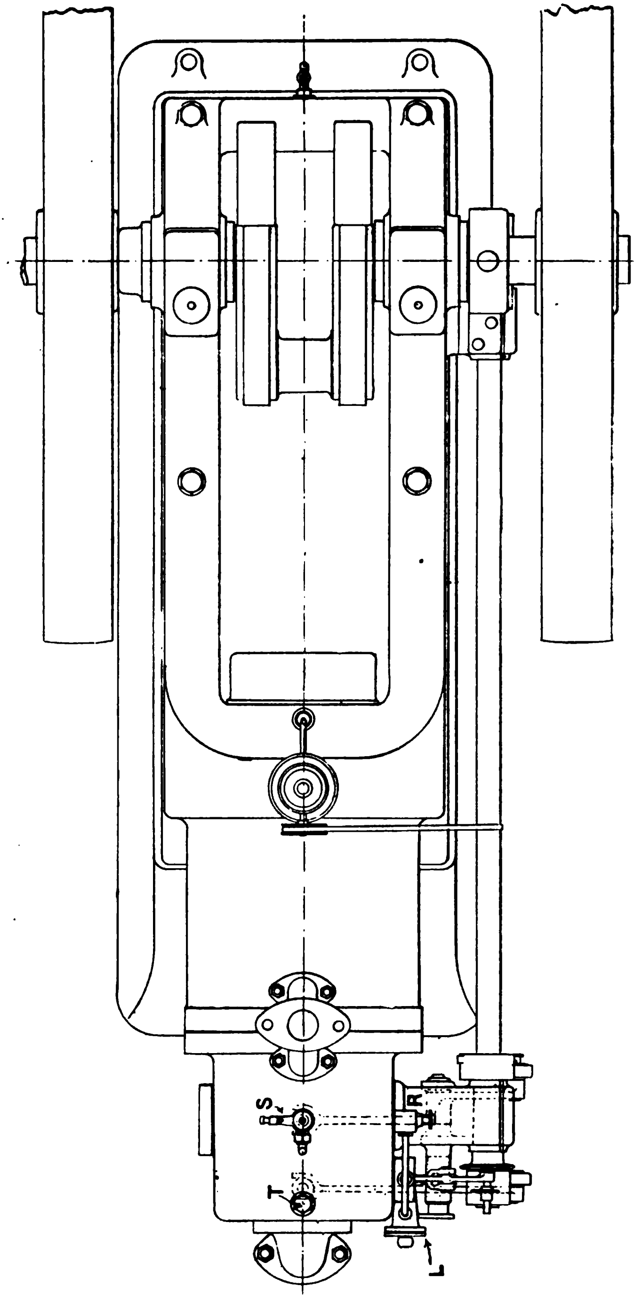


FIG. 17.—24 B.H.P. ROBEY ENGINE (LONGITUDINAL SECTION)



18.— 4 B.H.P. ROBEY ENGINE (PLAN)

Lanchester self-starter at S. The point of indicating this engine is at the extreme end of the combustion chamber at T.

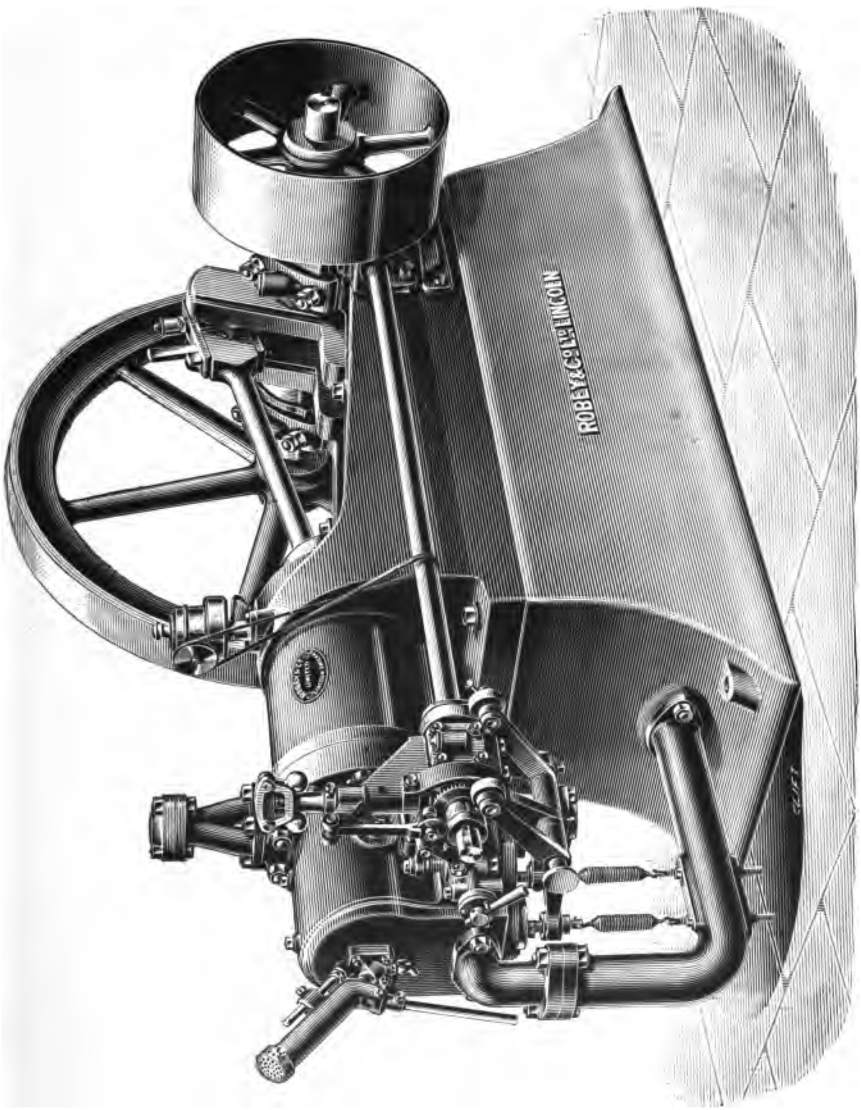


FIG. 19.—24 B.H.P. ROBEY ENGINE

The form of connecting rod used is very unusual in the gas engine, the large end being fitted with a strap, gib, and cotter.

which, as the impulse is taken only on the outward stroke, may be light, and yet permit of very fine adjustment. The cranks are of the slotted form and balanced on the webs, a practice

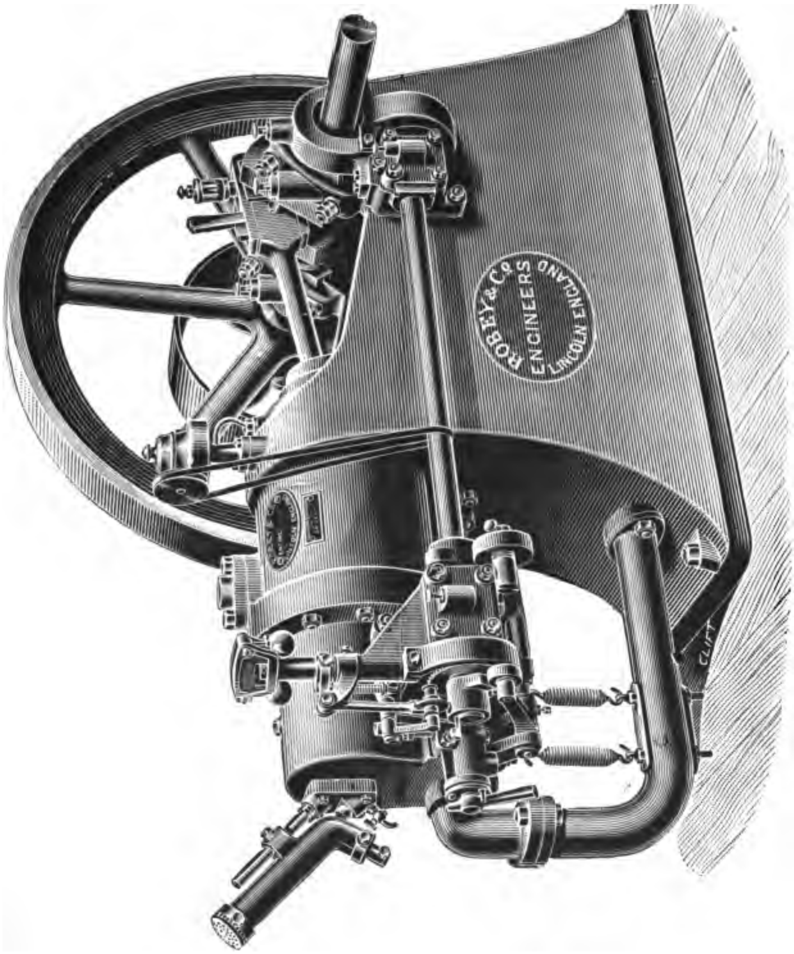


FIG. 20.—5 B.H.P. ROBEY ENGINE

strictly adhered to in all engines giving above 8 B.H.P. The pistons are of unusual length and as light as possible.

The Richardson type of governor is used, and the side shaft is fitted with adjustable bearings; and all engines are arranged to run in either direction.

In fig. 20, which is the form of engine used for the sizes ranging from $2\frac{1}{2}$ to 8 B.H.P, the only modification from that of fig. 19 is that the bed and base are in one casting, and the cranks are not balanced on the webs; and fig. 21 represents their smallest size of engine, on which an inertia governor of a simple form is substituted for the centrifugal one.

The tendency of all makers in designing large powers of gas engines is to arrange them in the girder form, and figs. 22, 23, and 24 are the elevation, plan, and perspective elevation of a 100 B.H.P. of this type.

FIG. 21.—$\frac{1}{2}$ B.H.P. ROBEY ENGINE

Any part can be detached for examination and repairs without interfering with any other part of the engine, and readily put together again by means of a few turned bolts. The main girders are tied together by a large foot, yet, when completed, form a substantial structure, in which the strains are very evenly distributed. The governing gear has all the advantages of the centrifugal governor, and a broad striking edge, the disturbing action being practically *nil*. The combustion chamber is fitted with manholes, which, besides serving as a means of cleaning out the cores at the foundry, are useful, when bad water is used, in keeping the jacket face from mud, and the

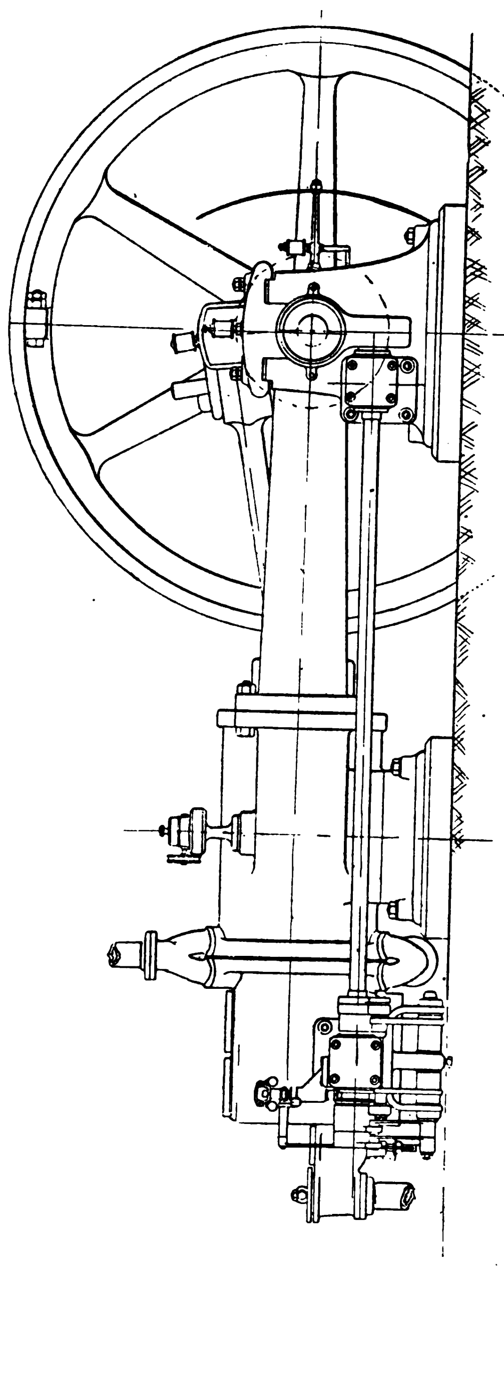


FIG. 22.—100 B.H.P. ROBEY GIRDER TYPE ENGINE (ELEVATION)

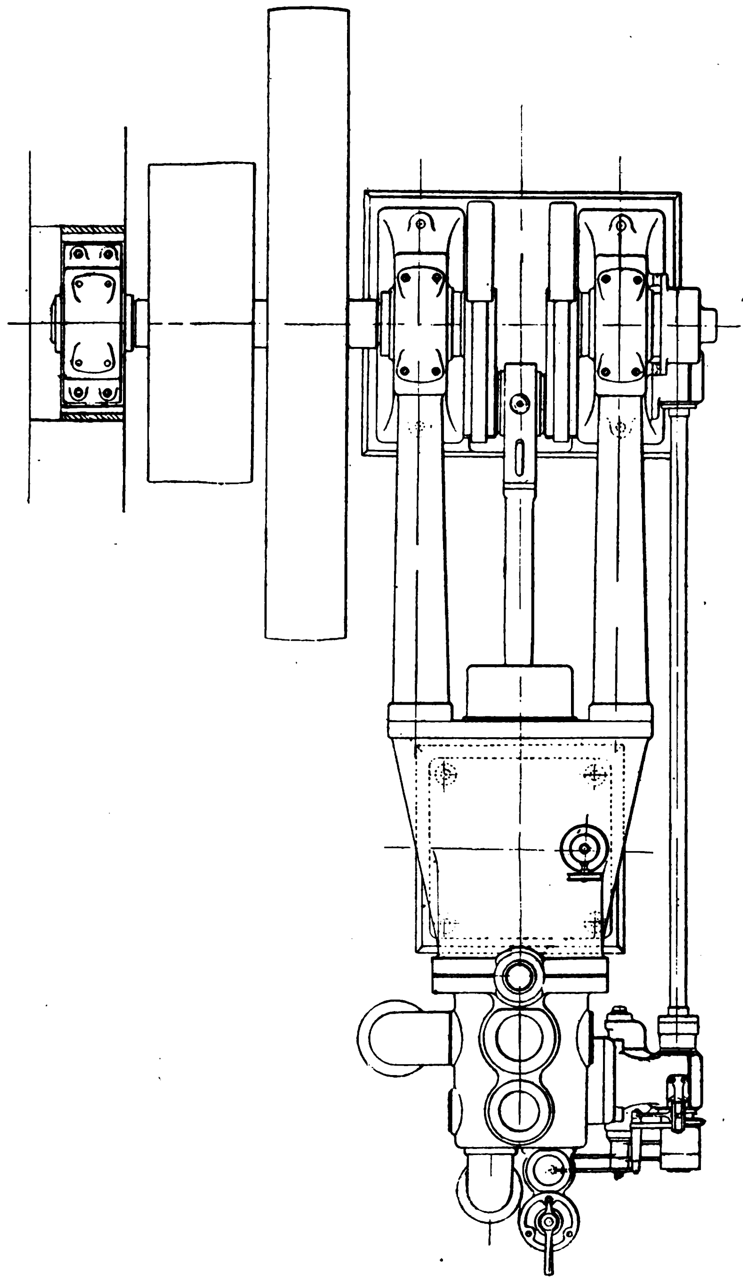


FIG. 23.—100 B.H.P. ROBEY GIRDER TYPE ENGINE (PLAN)

covers being made specially thin, act as safety doors in case of frost.

The bearings are in four pieces, the adjustment of which is arranged by wedges on the side opposite which takes the explosion. The length of the centres of the connecting rod is not less than three times the length of the stroke, and as balanced cranks are used the strains are greatly reduced. Only one flywheel with barring teeth and a water trough (for testing purposes) is fitted; but an outer bearing and pedestal is provided, as the flywheel has to be of necessity very large and heavy.

The crank is fitted with a neat arrangement of centrifugal lubrication for long-continuous running.

The Lanchester system is the method of self-starting used by this firm.

ROBEY GAS ENGINES

Maximum b.h.p.	Speed (Revs. per Minute)	Over all Dimensions		Approximate Weight of Engine	Size of Flywheels		Driving Pulley		Cooling Water
		Length ft. in.	Width ft. in.	cwts. qrs.	Diam. ft. in.	Width in.	Diam. in.	Width in.	cub. ft.
½	400	3 3	1 9	5 0	2 0	3	11	2½	8
1¼	350	3 9	2 1	7 2	2 6	3	11	3	10
2	300	4 6	2 8	9 2	3 0	3½	12	5	10
2½	230	5 0	2 5	14 0	3 0	3½	12	5	10
3¼	230	5 6	3 0	17 0	3 6	4½	12	6	28
3¾	220	5 9	3 3	19 2	3 6	4½	17	6	28
5	220	7 0	3 6	27 0	4 0	4½	20	7	28
6	220	7 0	3 6	27 2	4 0	4½	20	7	28
8	220	7 3	3 9	34 0	4 6	5	22	8	56
9	200	7 6	4 3	38 0	5 0	5	24	9	56
11½	200	8 9	4 6	56 2	5 0	6	24	9	56
13½	180	9 9	4 9	60 0	5 0	7	24	10	56
16	180	10 0	5 0	69 0	5 0	7	27	12	84
18	180	10 0	5 0	70 0	5 6	6	30	12	84
24	180	10 6	5 6	90 0	5 6	7	36	12	84
31	170	12 0	6 0	107 0	5 6	9	48	14	112
36	170	14 0	7 9	160 0	5 9	10	54	16	130
42	160	14 3	7 9	180 0	6 6	10	54	18	150
55	160	14 6	8 0	220 0	7 3	12	—	—	—
76	150	14 9	8 3	280 0	10 0	12	—	—	—
100	140	15 3	8 6	355 0	10 0	15	—	—	—
120	140	15 6	8 6	375 0	10 0	18	—	-	—

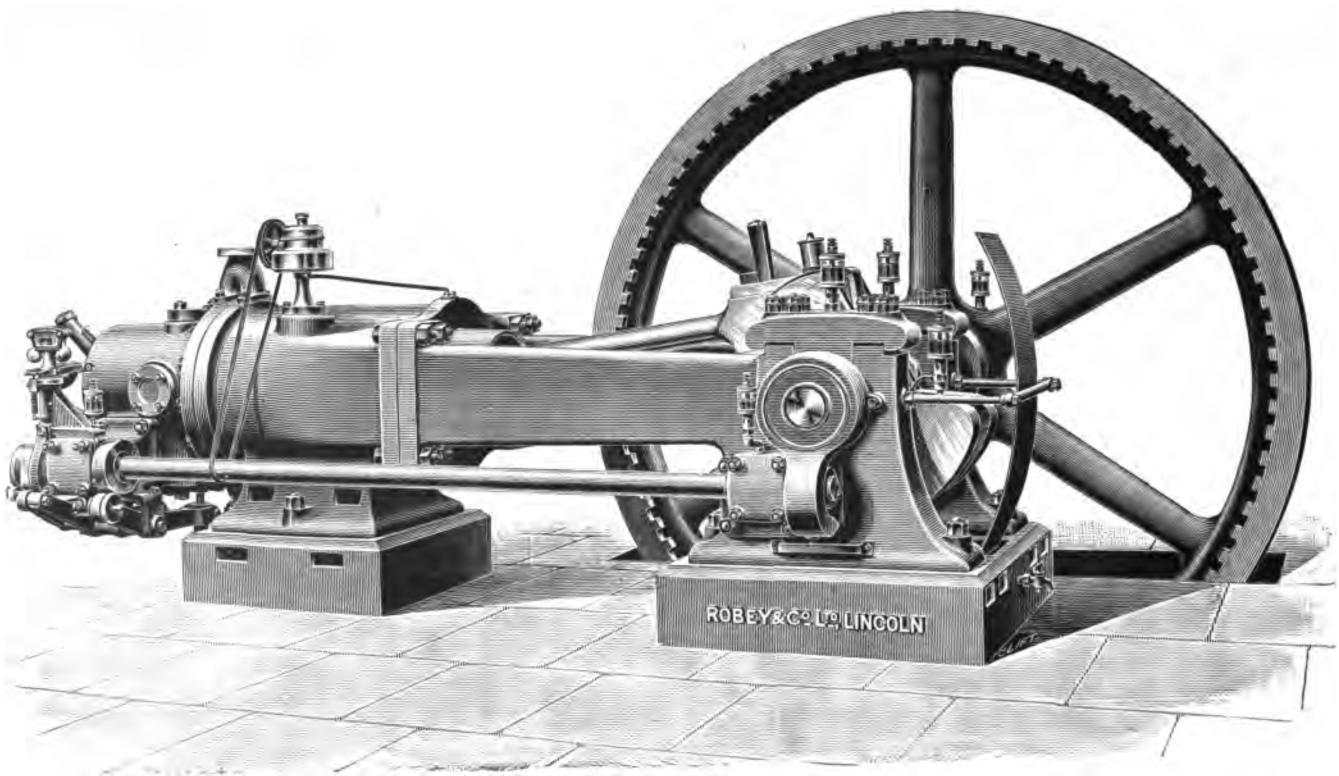


FIG. 24.—100 B.H.P. ROBEY GIRDER TYPE ENGINE

Tangyes (Limited), Birmingham

Few firms have spent so much time and money as Messrs. Tangyes in endeavouring to secure a marketable gas engine, and a walk through their museum at Cornwall Works, Soho, Birmingham, is an education in itself, for every form of engine from the Lenoir to the four cycle type, in various stages and in all sizes, trace the history of their experiments—all, however, to be discarded as so much waste effort, except the experience gained, when the 'Otto' patent rights expired; for Messrs. Tangyes were one of the earliest firms to take advantage of the prestige gained by the 'Otto' engine when the right to make them was no longer confined to Messrs. Crossley Brothers.

Their designs differ from Crossleys' engine in that the main cylinder and combustion chamber are made in two pieces, instead of one, whilst retaining the practice of bolting the cylinder to the main body of the engine. In the large sizes the valves are in the direct line of the explosion. In all sizes the ignition port passage is as short as possible—in fact, this has been obtained by sacrificing the appearance of the back end. However, a short ignition passage possesses many advantages, and more useful effect from the explosion can be obtained in this way than by passing round sharp corners.

Figs. 25, 26, 27, and 28 are part section and external elevation of a 3 H.P. NOM. engine. The air and gas inlet C, it will be seen, are in this size placed at the extreme end of the combustion chamber, on the centre line, whilst the exhaust valve box F is bolted to the side of the cylinder. The joint, however, in this engine would not have the same tendency to break as in some other forms, from the fact that there is no water jacket surrounding it, and the joint surfaces can be larger. The connecting rod centres are not less than three times the length of the stroke, and all engines below 16 H.P. NOM. are fitted with bent cranks. Automatic ignition is used on engines below 7 H.P. NOM., and a peculiar form of inertia governor on engines up to 10 H.P. NOM. Referring again to the sections (figs. 25, 26, and 27), it will be seen that the water jacket of the

combustion chamber A is in direct communication with the jacket in the cylinder B, and all water has to pass through holes

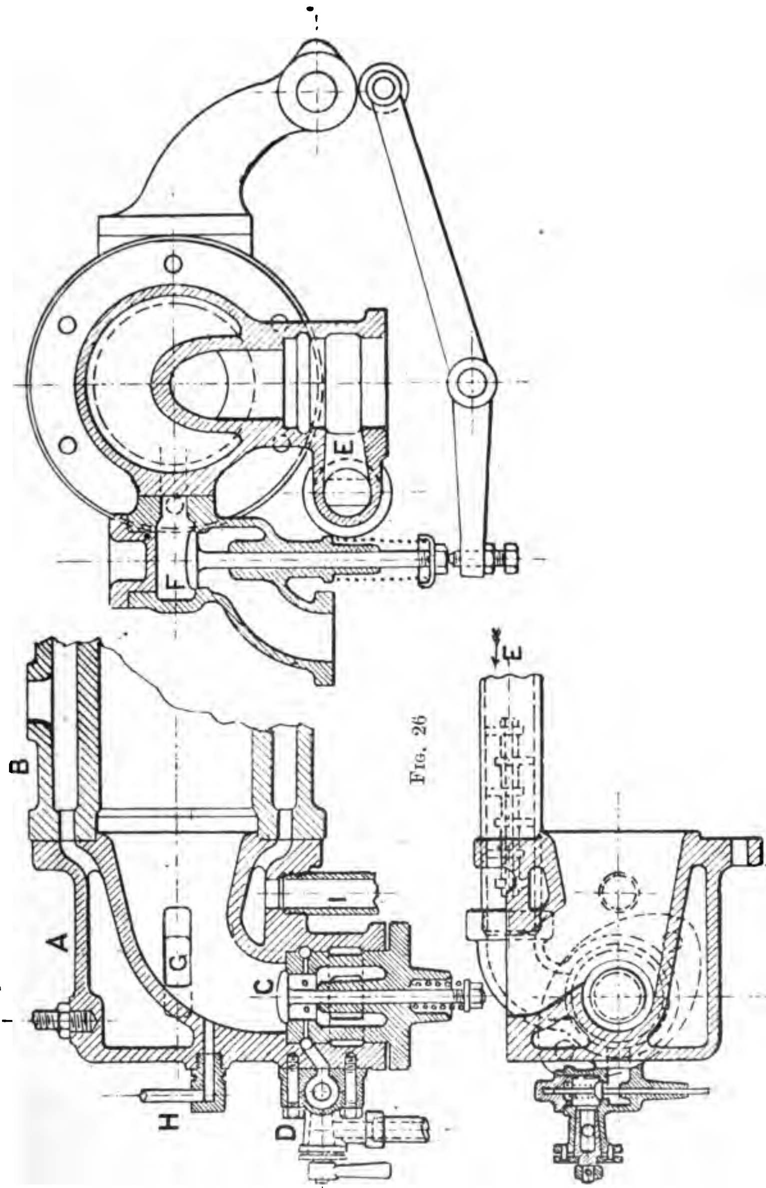


Fig. 27

Fig. 25

Fig. 26

Figs. 25, 26, 27.—3 h.p. nom. Tangye engine (combustion chamber)

made in the joint, as the water inlet I is in the back end and the outlet J in the main water jacket, making it somewhat

FIG. 28.—3 H.P. NOM. TANGYE ENGINE

difficult to keep this joint thoroughly tight. Fig. 29 represents a 12 H.P. NOM., the design of which only differs from the 3 H.P. in that the base is made in two parts instead of one, and

is fitted with a centrifugal governor, two flywheels, and arranged with a timing valve. In the larger size, however,

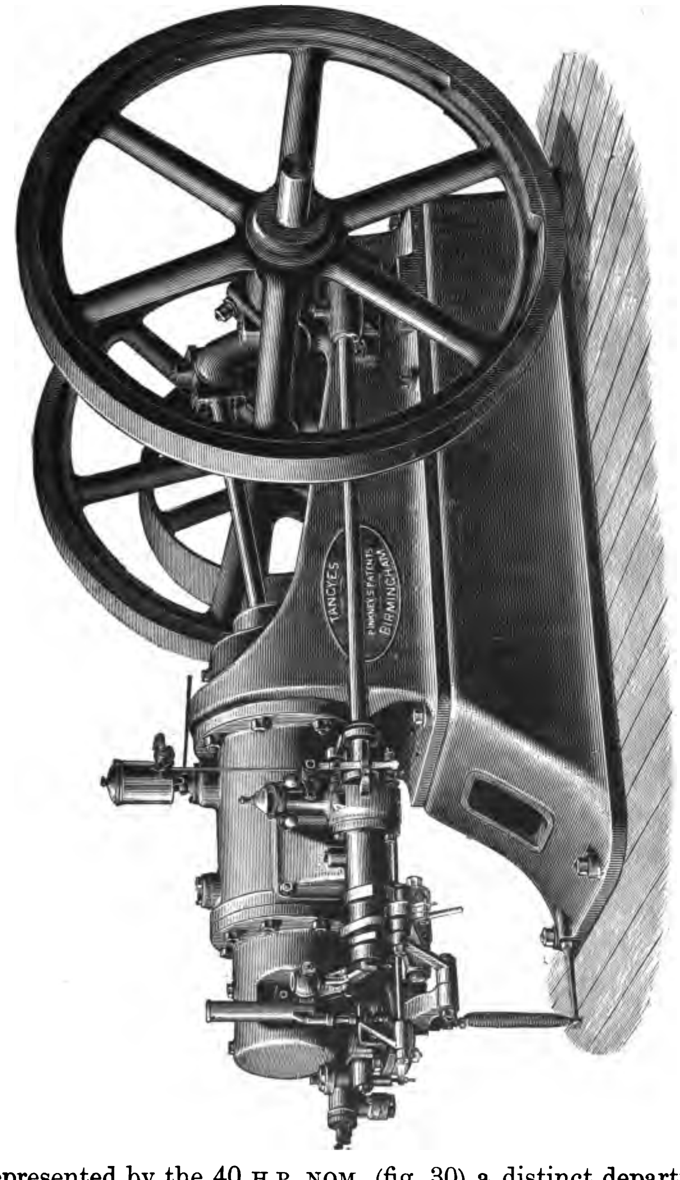


FIG. 29.—12 H.P. NOM. TANGYE ENGINE

represented by the 40 H.P. NOM. (fig. 30) a distinct departure is made. The separate base is dispensed with, the engine being

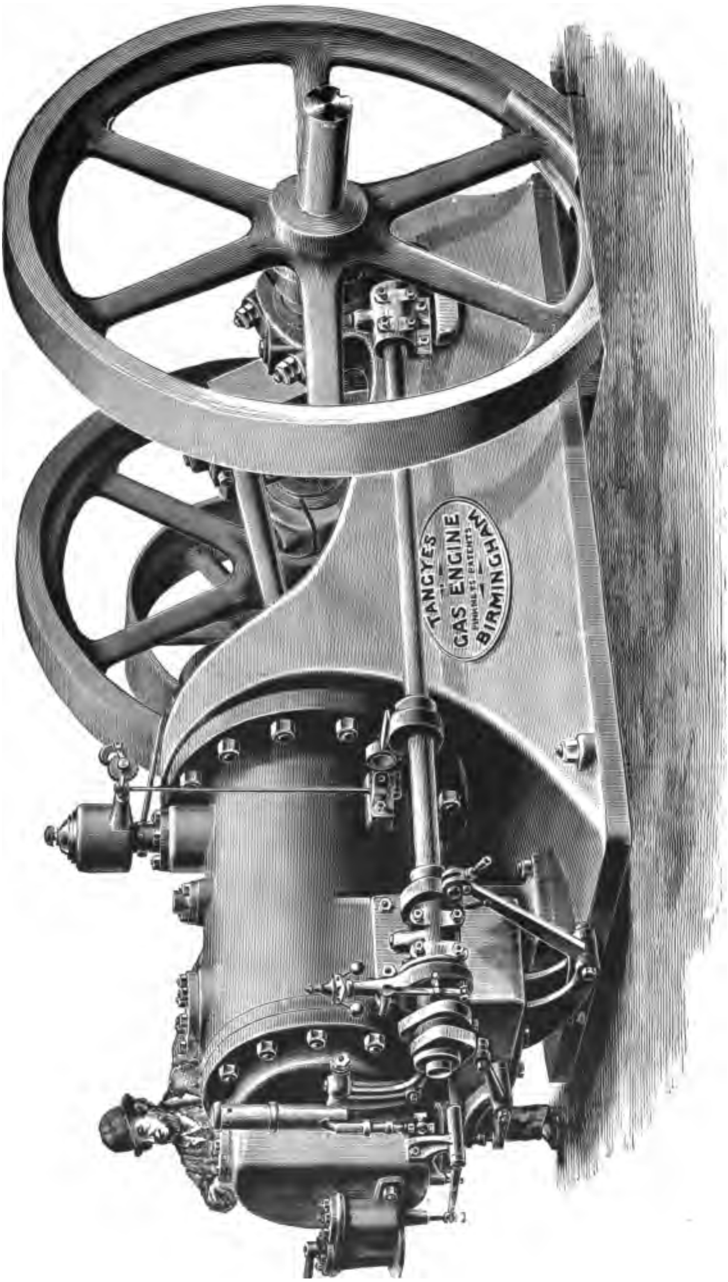


FIG. 30.—40 H.P. NOM. TANGYE ENGINE

kept very low, with the bed extended well under the cylinder, which is supported by means of a foot at the extreme end of it. The exhaust valve is placed in the main cylinder casting on the centre line, and the air, gas, and timing valves in the short back cover.

This firm have recently constructed an engine having a single cylinder 24 inches diameter, with a stroke of 30 inches, intended to run at 150 revolutions per minute, which it is said will develop 196 I.H.P. when using producer gas; and in order to mitigate the difficulties experienced in lifting the exhaust valve against the terminal pressure, which in this engine would be about one ton upon the head of the valve, they have arranged an auxiliary valve which, whilst actuated by the same lever, is lifted in advance of the main one.

TANGYES' GAS ENGINE

Nom. h.p.	B.h.p. (Maximum)	I.h.p. (Maximum)	Speed (Revs. per Minute)	Size of Fly-wheels		Driving Pulley		Diam. of Cylinder	Length of Stroke	Diameter of Crank Shaft
				Diam. in.	Width in.	Diam. in.	Width in.	in.	in.	in.
Vertical										
½	2	2¾	230	36	3½	10	5	—	—	—
½	2¼	3	230	36	3½	10	5	—	—	—
1	2¾	3½	200	44	4	12	6	5	10	1⅞
1½	3½	4½	200	44	4	12	6	—	—	—
Horizontal										
½	2	2¾	230	36	3½	10	5	—	—	—
¾	2¼	3	230	36	3½	10	5	—	—	—
1	2¾	3½	225	39	4	12	6	5	10	1⅞
1½	3½	4½	200	44	4	12	6	—	—	—
2	4¼	5½	200	44	4½	16	7	—	—	—
3	6	7½	200	54	5	16	7	6	12	2¼
4	7	9	200	54	5	16	7	—	—	—
5	9	11	200	60	6	20	8	—	—	—
6	11½	13½	200	60	6	20	8	—	—	—
7	13½	16	180	60	6	24	10	8½	16	3¼
8	15	17½	180	60	6	24	10	—	—	—
9	17	20	180	60	8	27	12	—	—	—
10	19	22	180	60	8	27	12	10	18	4
12	23	27	180	60	8	30	13	—	—	—
14	31	36	170	66	8	36	15	11	18	—
16	36	42	170	66	8	42	17	13	21	5
20	43	50	160	72	9	48	19	13½	22	5½
25	55	65	160	72	9	48	19	15	22	—
30	73	85	160	81	10	54	21	17	24	—
35	85	100	160	90	10	54	23	18	24	—
40	98	115	160	90	11	54	23	19	24	—
		Producer Gas 196	150					24	30	

With such dimensions and forces inherent in these large engines, the difficulties are not in the construction of an engine to withstand the heavy pressures so much as in overcoming the results of these forces when aggravated by the differential stresses resulting from the high temperature of combustion and unequal effect of the cooling water in the jacket.

In these large engines, when working at full load and using high compression, the combustion chamber is liable to become so hot that early firing ensues, the incoming charge being fired before end of compression stroke.

The above engine, like all Messrs. Tangye's large sizes, is fitted with their hand-pressure starter.

J. E. H. Andrew & Co. (Limited), Reddish

This firm commenced making gas engines as far back as 1878, in which year the late Mr. Andrew acquired the rights of the Bisschop engine at the Paris Exhibition, and continued manufacturing that type only until 1883, when they brought out the first Stockport engine, designed to give an impulse every revolution when working at full power, of which type they manufactured some thousands, and forming, before the expiry of the 'Otto' patents, the most formidable rival Messrs. Crossley had; but, like all the other engines, the Stockport, as then known, disappeared when those rights expired. Fig. 31 is a part sectional elevation, fig. 32 a sectional end elevation, and fig. 33 a perspective elevation of a 21 B.H.P. engine. The distinguishing features of this firm's designs are, that up to 85 B.H.P. the bed and cylinder are cast in one, and the back cover or combustion chamber attached to it by bolts, which go through its whole length. The air valve box is bolted to the end of the combustion chamber and is water-jacketed, the air inlet pipe passage forming part of the cylinder casting, opening into and fitted with baffle plates in the base. The exhaust valve box is bolted to the side of the combustion chamber, not in the direct line of explosion, and is also water-jacketed. No gas cock is fitted other than that on the gas bag on most of the sizes. The method of providing against the effects of frost is by making the metal

forming the extreme end very thin, so that this point should be the first to give when the water expands in freezing.

In their 54 B.H.P. engine (shown in fig. 34) the centre line is kept very low and the bed extended well under the

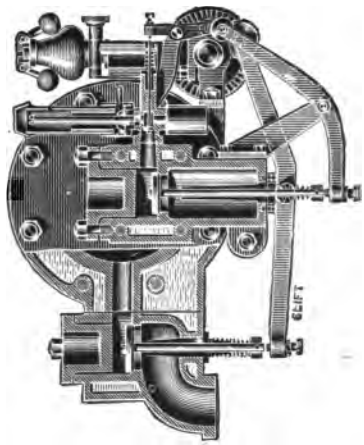


FIG. 32

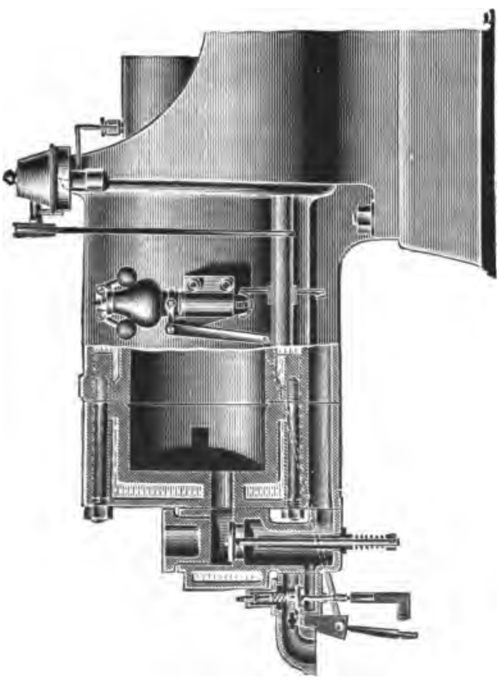


FIG. 31

FIGS. 31, 32.—21 B.H.P. STOCKPORT ENGINE

cylinder. A centrifugal governor combined with a momentum arrangement is used, but in all other respects is designed on the lines of the 21 B.H.P. The vertical engine shown in fig. 35 is

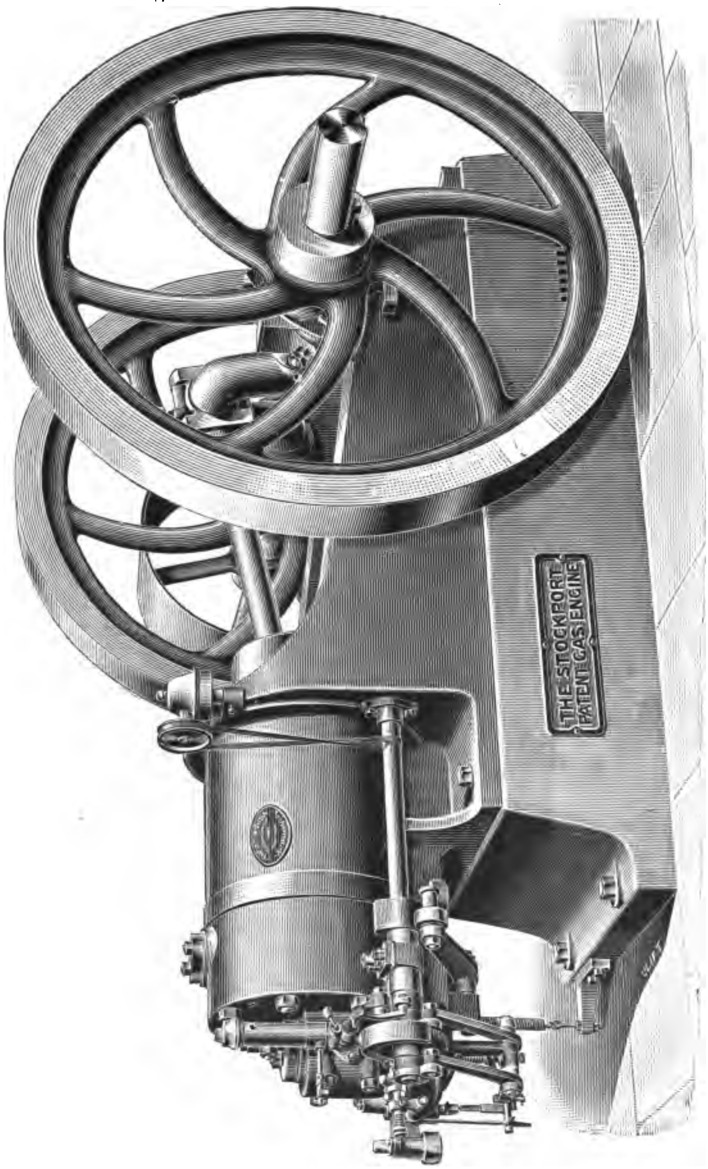


FIG. 33.—21 B.H.P. STOCKPORT ENGINE

a 5 B.H.P. and, like the smaller horizontal ones, is fitted with a vibrating governor and tube ignition.

All the engines dealt with hitherto have been engines in

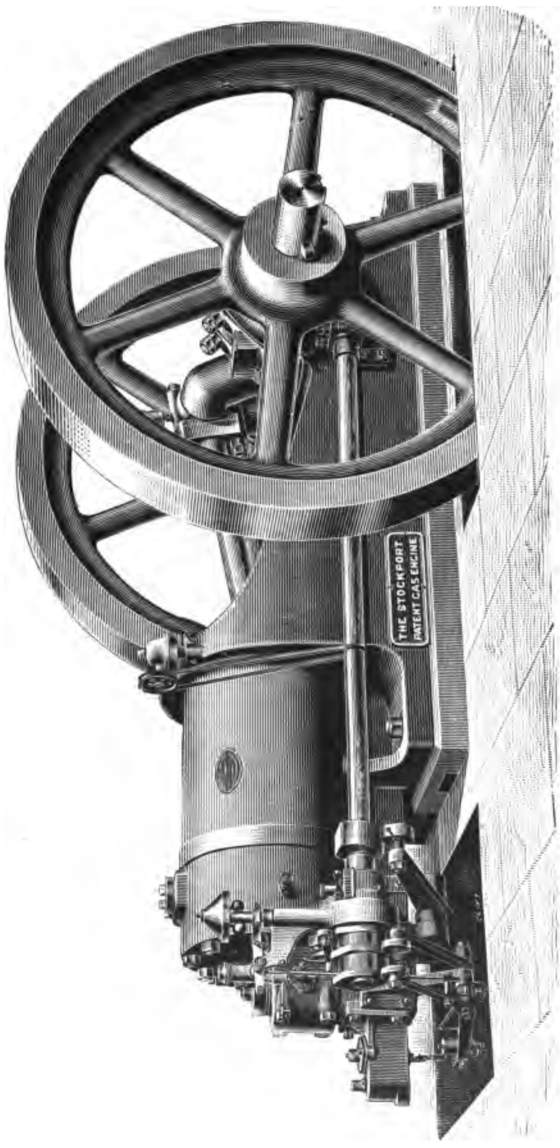


FIG. 34. – 54 B.H.P. STOCKPORT ENGINE

which the cylinder has been either overhung from the main casting carrying the bearings, or supported with a foot; but in

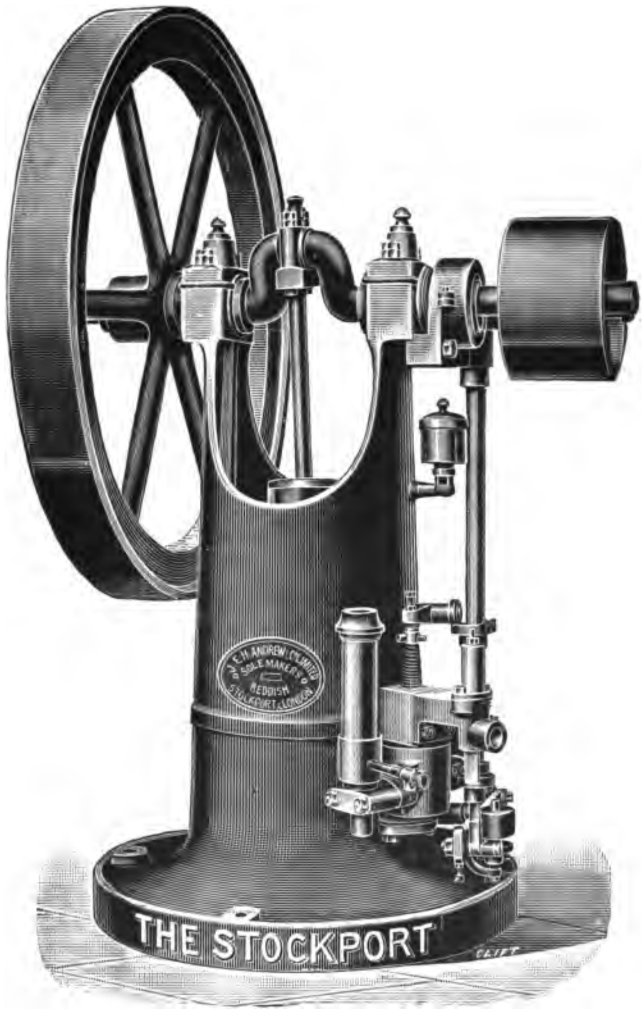


FIG. 35.—5 B.H.P. STOCKPORT VERTICAL ENGINE

figs. 36, 37, and 38 are seen engines in which the cylinders and main bearings are bolted to a flat frame; and it is claimed by the makers that a firmer grip upon the foundations is obtained

without overhanging the cylinders. The piston is unusually short, but is supported by a slide block connected to it by a rod.

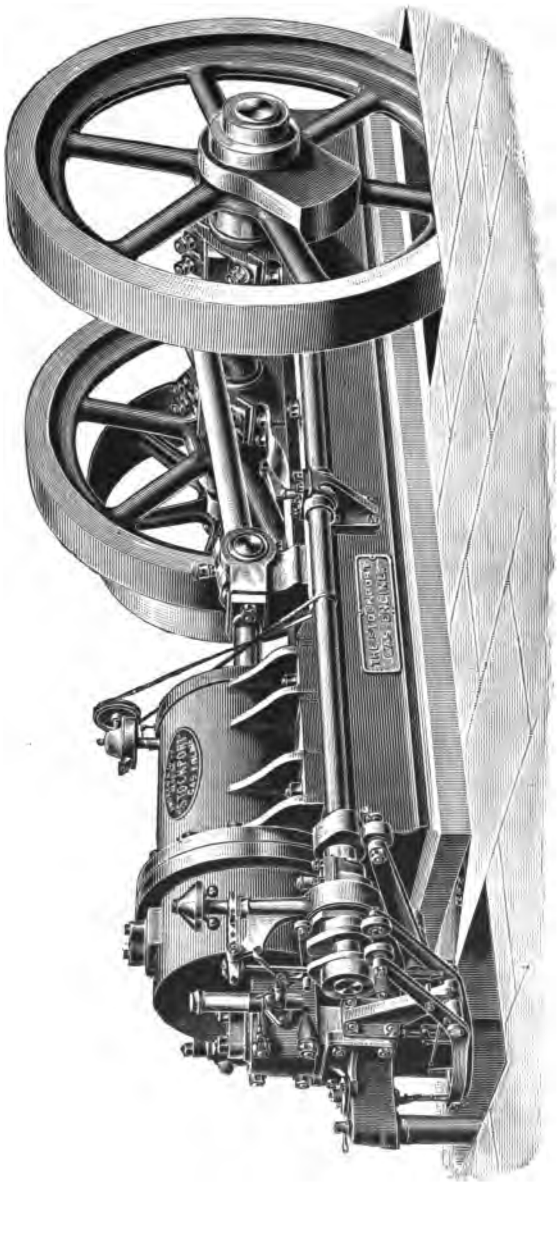


FIG. 36.—85 B.H.P. STOCKPORT ENGINE

The crosshead pin and brasses, however, by this arrangement are easy to get at for adjustment. The 85 B.H.P. (fig. 36) has a cylinder 18 inches diameter and 24 inches stroke, in which the

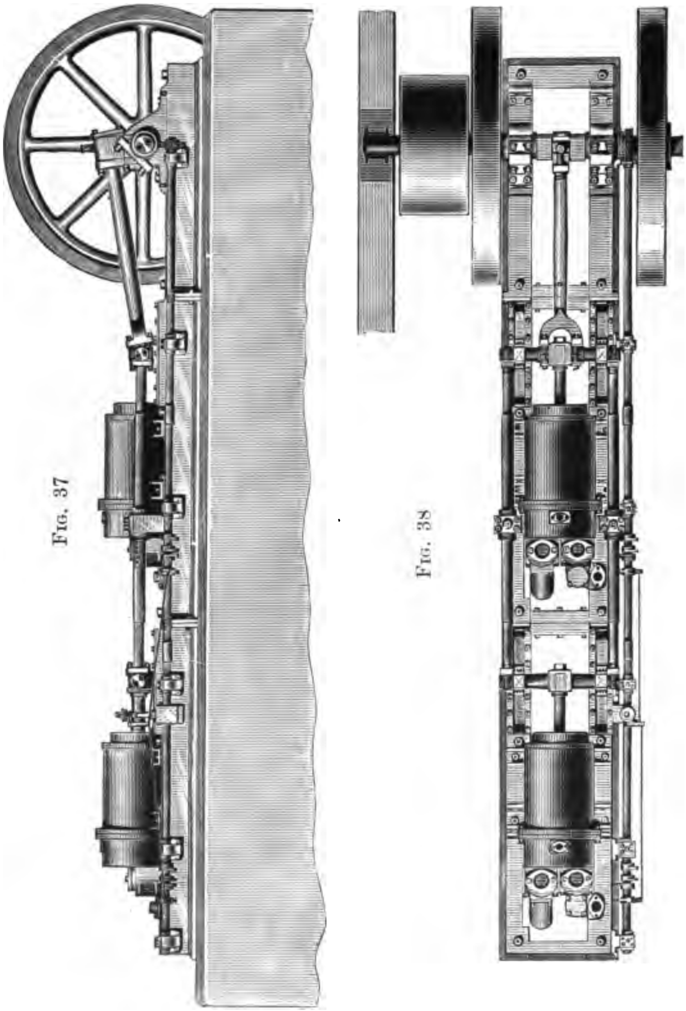


Fig. 37

Fig. 38

Figs. 37, 38.—400 B.H.P. STOCKPORT TANDEM ENGINE

valves are arranged as in figs. 31, 32, and 33, is fitted with a bent crank, and balanced by means of weights placed between the arms of the flywheels near the boss. Figs. 37 and 38 are

an elevation and plan of a tandem engine, having cylinders $25\frac{1}{2}$ inches diameter and 36 inches stroke, which, when running at 120 revolutions per minute and working with coal gas of 16 candle-power, it is stated, will develop 400 B.H.P., and 330 B.H.P. when working with producer gas. It is, however, impossible to give any reliable data as to its B.H.P. or the gas consumed, as there are several other engines working from the same producer plant.

The cycle of operations in this engine is that shown in fig. 1 at B, and also in fig. 3—that is, an impulse every revolution when working at full power. The two pistons are connected by side rods supported at their ends by slide blocks, the connecting rod being common to both. The blow from the explosion of the charge delivered by the connecting rod at centre of cross-piece gives the latter severe bending, whilst the action

STOCKPORT GAS ENGINES

Brake or Effective h.p.	Speed (Revs. per Minute)	Dimensions of Engines		Approx. Weight of Engines	Size of Fly-wheels		Driving Pulley		Diameter of Cylinder	Length of Stroke	Diameter of Crank Shaft
		Length ft. in.	Breadth ft. in.	cwts. qrs.	Diam. ft. in.	Width of rim in.	Diam. in.	Width in.	in.	in.	in.
Vertical											
1½	200	3 4	3 0	13 2	3 4	3½	10	6	—	—	—
5	200	3 6	3 3	22 2	4 2	4	18	7	—	—	—
Horizontal											
1	From	4 9	2 6	9 2	2 9	2	9	5	—	—	—
2	190	5 3	3 0	13 2	3 0	2½	10	6	—	—	—
3	to	5 9	3 9	18 0	3 2	3	14	6	—	—	—
4	220	6 9	4 0	27 3	3 10	4	16	7	—	—	—
7	From	7 0	4 3	32 0	3 11	4	18	7	—	—	—
9	190	8 0	4 6	38 0	4 3	4¾	21	8	—	—	—
10½	to	8 3	5 0	45 2	4 4	5	21	8	—	—	—
12	210	8 6	5 3	53 0	4 8	5	23	9	—	—	—
15	From	8 9	5 6	60 1	4 9	5½	23	10	—	—	—
17½	175	9 0	6 0	66 0	5 2	6	27	12	—	—	—
21	to	9 3	6 3	74 3	5 3	6	32	12	—	—	—
26	190	9 9	6 6	90 0	5 3	6	36	12	—	—	—
	From										
30	160	10 0	6 9	100 0	5 4	6	44	14	—	—	—
35	to	10 6	7 0	112 2	5 5	6	46	15	—	—	—
	175										
44	160	11 10	8 3	148 0	6 2	9	54	19	—	—	—
54	160	12 0	8 3	190 0	6 3	9	54	23	—	—	—
70	155	13 0	8 6	210 0	6 10	10	—	—	—	—	—
85	150	13 3	8 9	245 0	7 0	10	—	—	18	24	—
100	150	17 3	10 0	360 0	7 2	10	—	—	—	—	—
135	140	—	—	—	—	—	—	—	22	30	—
200	120	—	—	—	—	—	—	—	25½	36	—
Tandem											
400	120	—	—	—	—	—	—	—	25½	36	—

at its ends on the slide blocks is calculated to add greatly to the friction and resistance. Unlike their usual practice, the air and exhaust valves are placed on the end of the combustion chamber, one side shaft actuating the whole of the valves, and the gas inlet of both cylinders is under the control of one centrifugal governor.

The self-starter used by this firm is very simple and efficient.

Fielding & Platt, Gloucester

Messrs. Fielding & Platt's experiments in gas motors date back to 1879, from which year to 1890 they were engaged, like many other firms, in comparing other types with the now universal 'Otto.' The evolution of their present form of valves has been very interesting. However, a description of these is outside the scope of this treatise. It is difficult to understand why, when designing an engine to combine the many advantages of the girder frame, engineers should nullify those advantages by arranging the bearings so that the force of the explosion has to be taken up by the cap bolts, when it is as easy to arrange that the main casting shall be utilised for the purpose. Fig. 39 shows that this firm, like others, have fallen into this error, as in the 100 B.H.P. engine this defect is very pronounced. The girders and main bearings are in one casting, to which the cylinder is bolted, the bolts for which are, however, covered over with a loose ring. Although this gives the engine a very neat appearance, it does not admit of easy access to the bolts. The air and exhaust valves are carried in one box, forming part of the combustion chamber, the air valve being arranged at the top and the exhaust valve at the bottom. The governor and gear are of the ordinary dead-weight centrifugal pattern.

An illustration of the development of large power in gas engines is shown in figs. 40 and 41, wherein 180 B.H.P. is arranged to drive direct an air compressor at the high speed of 150 revolutions per minute. The distinctive feature is that the crank shaft, arranged between the back end of one cylinder and the front end of the other, is placed above the centre

line of the cylinder, to allow the rods coupling the two pistons to travel in a direct line under the crank shaft, one connecting

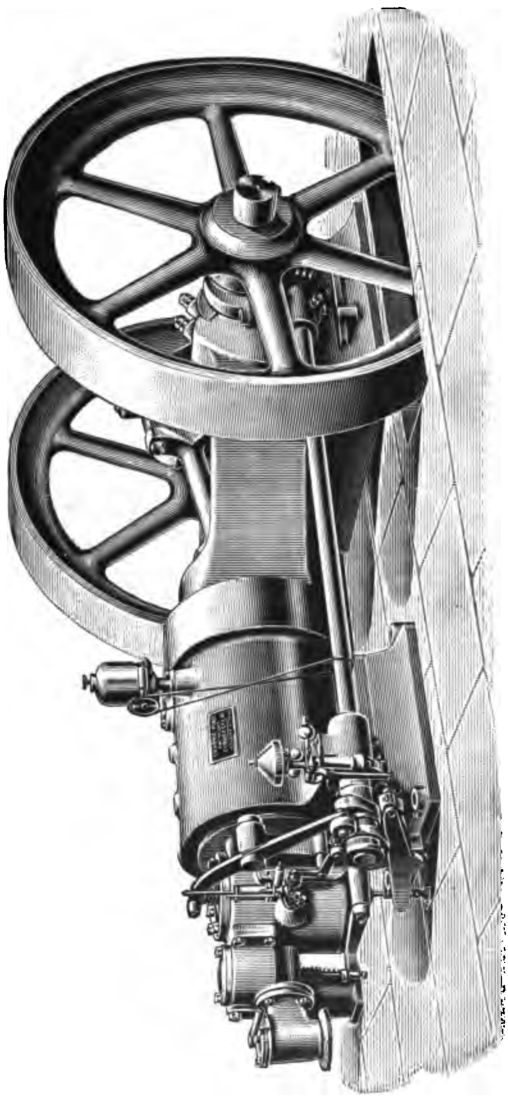


FIG. 39.—100 B.H.P. FIELDING ENGINE

rod serving the purpose of the two cylinders. The cycle of operations is the same as that shown in fig. 2 at B, and fig. 4—

that is, an impulse is obtained at every revolution when working at full power.

The compressor, which was constructed by Messrs. Johnson & Co., Stratford, London, is a two-stage one, compressing the air up to 40 lbs. per square inch above the atmosphere.

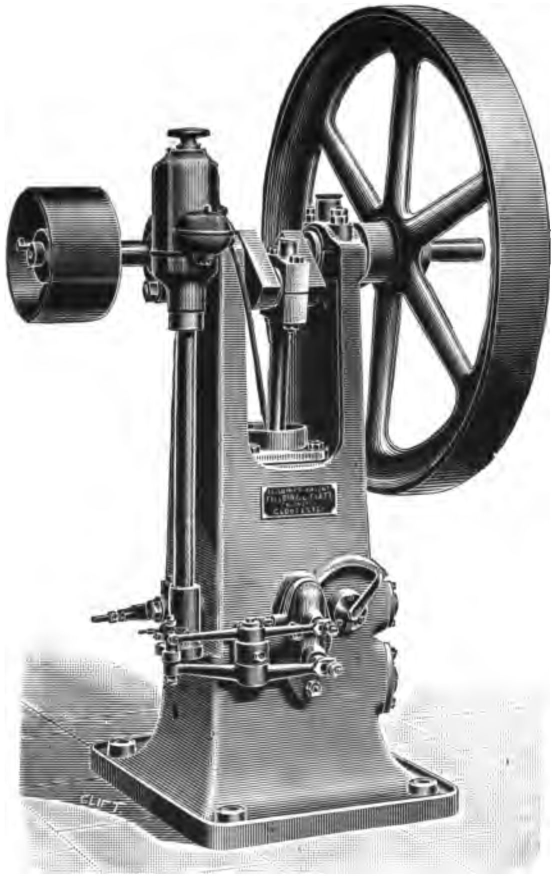


FIG. 42.—1½ H.P. NOM. FIELDING VERTICAL ENGINE

The engine is fitted with a Fielding high-pressure starter applied to one cylinder only. The makers state that a highly satisfactory test has been made with this plant, using producer gas, although the results were not sufficiently accurate for publication.

THE FIELDING GAS ENGINE

HORIZONTAL PATTERN

Single Cylinder

Nom. H.P.	I.H.P.	B.H.P.	Speed (Revs. per Minute)	Approximate Outside Dimensions: Length ft. in.	Approximate Outside Dimensions: Width ft. in.	Approximate Weight: Nett ton cwt.	Approximate Weight: Packed ton cwt.	Flywheels: Diam.	Flywheels: Width	Driving Pulley: Diam.	Driving Pulley: Width	Gas Pipe	Water Pipe	Exhaust Pipe	Meter	Diameter of Cylinder	Length of Stroke	Diameter of Crank Shaft
1	2¾	1·9	200	5 8	3 6	0 16	0 19	3 6	4½	12	6	¾	1¼	1½	10	—	—	—
2	5	3·75	200	6 6	4 1	1 5	1 9	4 0	4½	16	6	¾	1¼	1½	10	—	—	—
3	8	5·5	200	6 6	4 1	1 6	1 10	4 0	4½	16	6	¾	1¼	1½	15	—	—	—
4	10	8·0	200	8 3	5 1	1 16	2 0	5 0	5	20	8	1	1½	1½	20	—	—	—
6	13	10·3	180	9 0	5 2	2 18	3 4	5 6	6	24	10	1¼	2	2	30	—	—	—
8	18	14·4	180	9 0	5 2	3 17	4 4	5 6	6	27	12	1¼	2	2	50	—	—	—
10	22	17·6	180	10 0	6 6	4 13	5 0	5 9	7	30	12	1½	2½	2½	60	—	—	—
12	27	21·6	180	10 0	6 6	4 15	5 2	5 6	6	36	12	1½	2½	3	80	11½	18	4¼
14	34	27·2	170	10 0	6 6	5 0	5 6	5 6	7	48	14	1½	3	3½	120	—	—	—
16	42	35·7	160	12 0	7 10	6 18	7 6	5 9	7	54	18	2½	3	4½	150	—	—	—
20	50	42·5	160	12 0	9 8	7 19	8 8	5 9	9	54	18	3	4	5·	150	14½	22	—
30	—	—	160	—	—	—	—	—	—	—	—	—	—	—	—	17	27	—
35	100	80·0	160	13 6	10 0	12 16	13 7	7 3	10	54	18	4	5	6	250	—	—	—

VERTICAL PATTERN

Nom. H.P.	I.H.P.	B.H.P.	Speed (Revs. per Minute)	Length ft. in.	Width ft. in.	Nett cwt. qrs.	Packed cwt. qrs.	Flywheels: Diam.	Flywheels: Width	Driving Pulley: Diam.	Driving Pulley: Width	Gas Pipe	Water Pipe	Exhaust Pipe	Meter	Diameter of Cylinder	Length of Stroke	Diameter of Crank Shaft
½	2	1·3	200	3 0	2 11	10 0	12 0	3 0	4	9	5	½	1	1¼	5	—	—	—
1	2¾	1·9	200	4 0	3 4	14 2	1 62	3 6	4½	12	6	¾	1¼	1½	10	—	—	—
1½	3½	2·45	200	4 0	3 4	14 3	16 3	3 6	4½	16	6	¾	1¼	1½	10	—	—	—

The vertical engine shown in fig. 42 is a departure in design from those made by other firms, the valve arrangement being very neat and compact. These points, together with automatic tube ignition and an inertia governor, give a well-designed engine.

T. B. Barker & Co., Birmingham

Messrs. Barker & Co. claim an experience in gas engine manufacture extending over a long series of years, and ranging from an atmospheric engine to the present 'Otto' type, for some time paying considerable attention to the three-cycle engine; and tests conducted by independent authorities proved that even with this type very low gas consumptions were obtained.

Fig. 43 shows their 9 H.P. NOM. size, the cylinder of which is fitted into the bed and held in its place by bolts passing through the water jacket. The valve gear is exceedingly simple, and the governor of the inertia type.

Their 16 H.P. NOM. engine, shown at fig. 44, has a cylinder 12 inches diameter and a stroke of 20 inches, and which gave most satisfactory results in an independent test, particulars of which will be found on pp. 240 to 248.

'FORWARD' GAS ENGINES

NOM. H.P.	Maximum B.H.P.	Approximate I.H.P.	Over all Dimensions of Engines		Approximate Weight of Engines	Driving Pulley		Normal Revs. per Minute	Diameter of Cylinder	Length of Stroke	Diameter of Shaft
			ft. in.	ft. in.	cwts.	Diam. in.	Width in.				
1	2¾	3½	5 8	3 4	15	12	5	200	—	—	—
2	4	5	6 10	3 7	20	18	6	200	—	—	—
3	5¼	7	7 0	3 9	24	20	7	200	—	—	—
4	8	10	7 3	4 0	30	21	8	200	—	—	—
6	11	13	8 9	4 9	36	24	9	180	—	—	—
7	12	15	9 0	5 0	40	24	9	180	—	—	—
9	16	20	10 4	5 11	56	28	12	180	—	—	—
12	21	27	10 6	6 0	64	30	12	180	—	—	—
14	29	35	10 6	6 6	85	33	14	170	—	—	—
16	34	40	10 8	6 8	92	36	14	170	12	20	4⅜
20	43	50	12 4	7 8	110	48	16	160	—	—	—
25	53	65	12 6	8 0	125	54	18	160	—	—	—

The cylinder and bed are in one casting, with a separate

base, the back cover, containing the gas, air, and exhaust valves, is water-jacketed, and is bolted to the end of the cylinder. The

FIG. 43.—9 H.P. NOM. 'FORWARD' ENGINE

practice of this firm is to fit engines of all sizes with bent cranks, automatic tube ignition, and to arrange the gear wheels which drive the side shaft between the bearing and the crank so that the flywheel or pulley may be brought close up to the bearing. The centrifugal governor fitted to this size can be

regulated whilst running in a very simple manner. The Lanchester starting system is adopted.

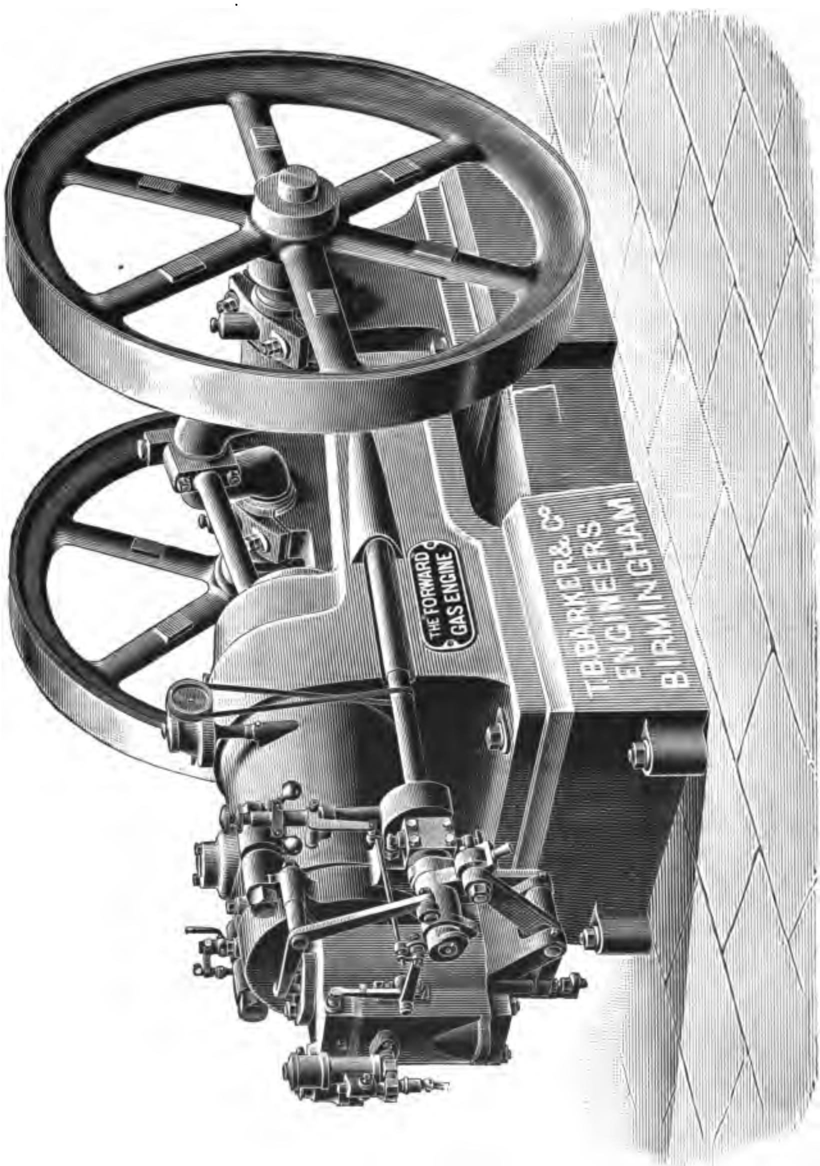


FIG. 44.—16 H.P. NOM. 'FORWARD' ENGINE

Wells Brothers, Sandiacre, near Nottingham

Whilst the history of this firm as gas engine makers does not date back beyond 1889, the fact that they were the first to demonstrate the possibility of starting a gas engine by pumping a charge of gas and air into the combustion chamber in 1889, and the advantage gained by using a positive scavenging method (in 1890), and at the Crystal Palace Electrical Exhibition in 1891 being able to obtain 1 I.H.P. with 16·5 cubic feet of London gas with an engine giving 27 B.H.P., is sufficient to give them the right to take a foremost place amongst gas engine manufacturers.

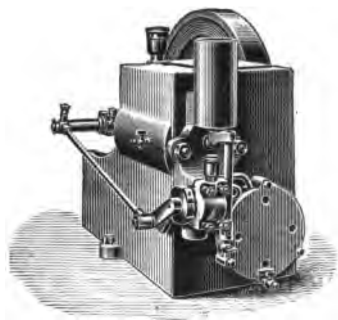


FIG. 45.—$\frac{1}{4}$ H.P. NOM. 'PREMIER' ENGINE

Fig. 45 shows their $\frac{1}{4}$ H.P. NOM. engine, which develops $\frac{1}{2}$ B.H.P. when running about 200 revolutions per minute.

One of the novel features in this engine is the manner in which the mixture is admitted by means of one intermittent rotary valve, which remains at rest with the exhaust port open when making idle strokes. The method of governing is interesting in that the engine may run idle 1, 2, 3 revolutions; not as in the ordinary engine, in which the idle revolutions must be 2, 4, 6, &c.

It is entirely self-contained, and does not require separate water tanks, the cooling water being contained in the bedplate, and its weight helps to steady the engine and prevents vibration.

Fig. 46 represents an ordinary engine of a larger size—viz. 9 H.P. NOM. The admission and exhaust valves are arranged at an angle with the centre of the combustion chamber. The overhanging part of the cylinder is small, the main casting very rigid, and three bearings are used for the crank shaft, the worm wheels for driving the cross shaft being arranged between the two smaller ones, and the flywheels are brought close up to them on both sides. Automatic tube ignition and a modified form of inertia governor is fitted.

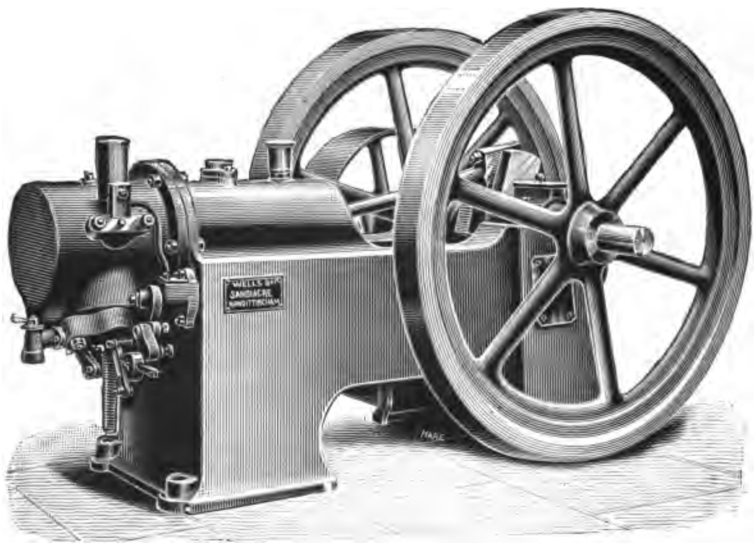


FIG. 46.—9 H.P. NOM. 'PREMIER' ENGINE

All the engines described hitherto have been of the ordinary trunk piston type. But fig. 47 is an external, fig. 48 a longitudinal section, and fig. 49 an end view of an engine arranged with a positive scavenging arrangement, as already mentioned, is interesting as being the first successful engine using the scavenging method.

The combustion chamber A is fitted with an air valve B and gas valve C, the exhaust valve D being arranged immediately

under the air valve. The air passage E leads to the air chamber F, in which works the air pump piston G, which serves as a guide

FIG. 47.—THE 'PREMIER' ENGINE, WITH SCAVENGER

also, attached to the motor piston H. The air reservoir I is situated in the base of the main casting J, the air entering

FIG. 49

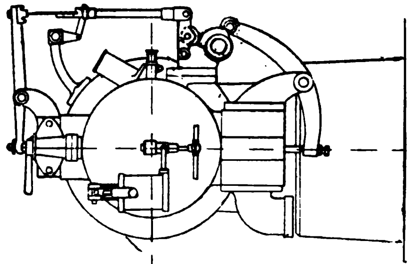
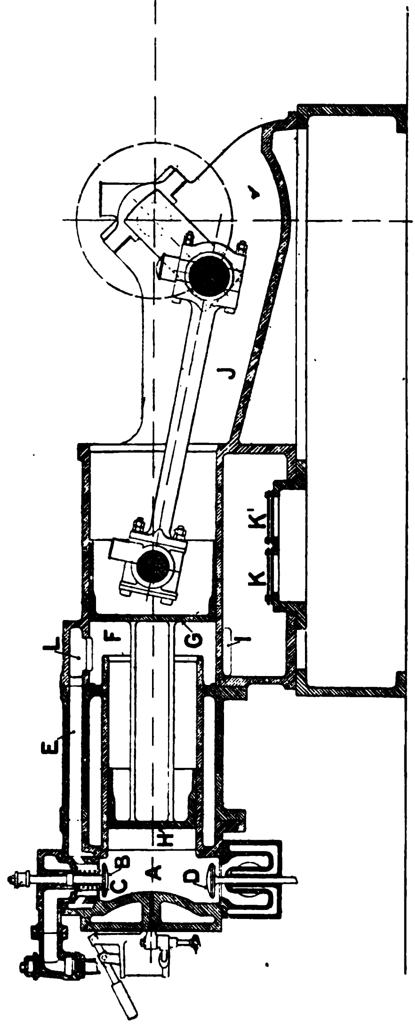


FIG. 48



FIGS. 48, 49.—THE 'PREMIER' ENGINE (WITH SCAVENGER)

through the automatic valve K K′. This chamber is in communication with the air pump by means of a passage L.

During the forward stroke a charge of air is drawn into the air chamber, which on the return stroke is slightly compressed, and enters the combustion chamber by means of the automatic air valve (this valve acts independently of the gas valve). If this return stroke were the exhausting one, the expulsion of the products must necessarily be assisted to a considerable extent, and the combustion chamber be almost filled with pure air. During the compression and explosion strokes there is a slight gain of power owing to the heating of the air, but as this heating is very slight, the gain cannot be reckoned upon.

Fig. 50 is a diagram taken from the air pump cylinder of a 30 H.P. NOM. engine. S is the suction line and C the compression lines, coinciding for both back strokes till the admission valve opens; then on the exhaust stroke the discharge line D D′ is horizontal, till the piston nearly comes to rest, when the drop is very rapid, owing to the exhaust valve being nearly full open, and the gases in the pipe in motion.

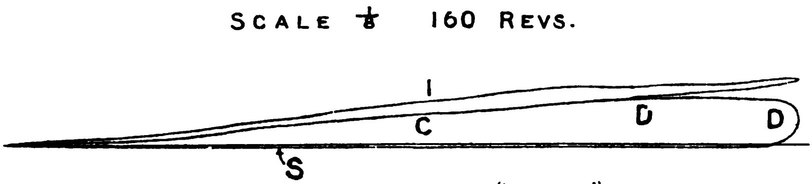


FIG. 50.—AIR PUMP DIAGRAM ('PREMIER')

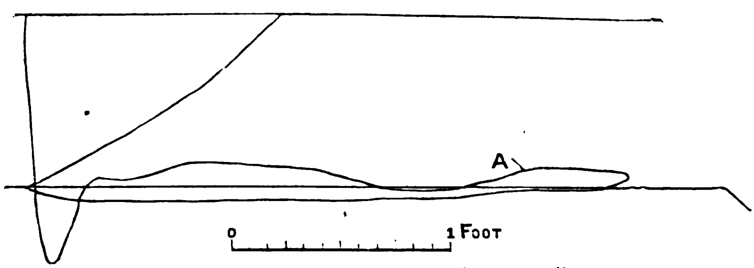


FIG. 51.—LIGHT SPRING CARD ('PREMIER')

Fig. 51 is a light spring card taken from the motor cylinder

of the same engine; the effect of the entrance of air in the cylinder is shown at A, near the end of the stroke.

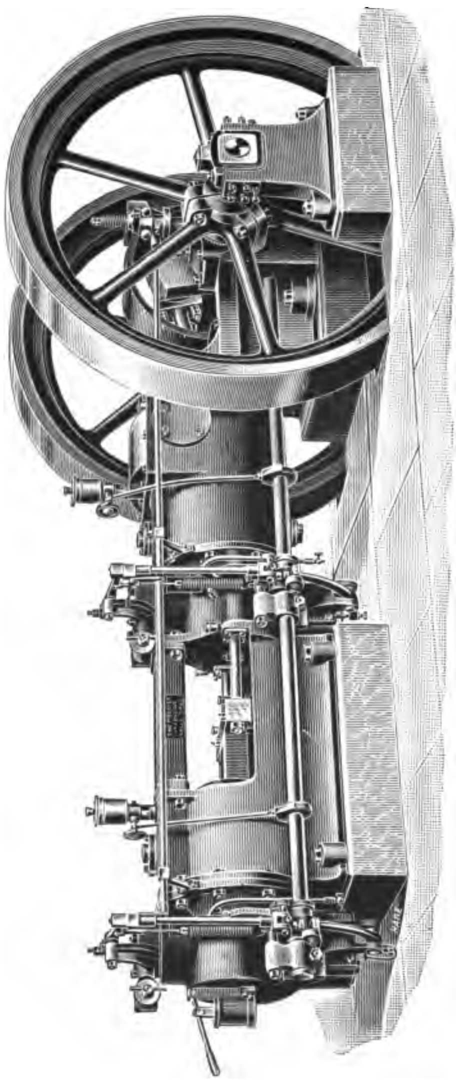


FIG. 52.—150 I.H.P. 'PREMIER' TANDEM ENGINE (WITH SCAVENGER)

The area of the air pump piston is 1·65 time that of the motor piston, or a difference of area of 0·65 time the motor

piston, which fraction multiplied by the mean pressure in the pump will give the equivalent deduction to be made from the effective pressure in the latter, in order to allow for loss of power in the pump.

The work absorbed in forcing the air through is, owing to free passages, very slight, as a reduction of $\frac{3}{4}$ to 1 lb. per square inch from the indicator card will cover it.

From a mechanical point of view the air cylinder is advantageous, as the front end of the piston remains cool and offers a large surface for taking the lateral thrust of the connecting rod, and a cool bearing for the piston pin.

Fig. 52 is an external elevation of a tandem 'scavenging' engine, which will indicate 150 H.P. with coal gas, and one-fifth less with Dowson gas. With Sandiacre gas, the consumption is 15 cubic feet per I.H.P. per hour.

Referring to fig. 52, it will be seen that the two pistons are coupled by side rods passing through the cylinder jacket, though not in contact with the cooling water. The pistons are well supported by a slide block working between the two cylinders. A governor of the centrifugal type mounted on the crank shaft actuates the gas pecker lever on each cylinder. When working at full power an impulse is obtained for each revolution of the crank shaft.

The design of this engine is well thought out, and is admirably adapted for hard work without undue heating.

Clarke, Chapman & Co. (Limited), Gateshead-on-Tyne

All the engines described have been worked on the 'Otto' cycle, with fixed air and gas inlet, the latter being in some cases varied by a graduated cam, tube ignition, and side shaft for operating valve levers. In this engine there is a new departure, inasmuch as the lifting drop valves and tube ignition is dispensed with, the system adopted being known as 'Butler's.'

Fig. 53 is an external elevation; fig. 54 a sectional plan, and fig. 55 a cross section, clearly show the whole arrangement.

It will be seen that only one four-chambered equilibrium valve is used, the speed of which is one-fourth that of the crank, and controls the various functions of the supply of gas, air, and exhaust. The gas and air pass through an inspirator, where they get properly mixed on their way to the combustion chamber.

The speed regulator is actuated by a flywheel governor, which opens or closes the regulator valve so as to admit a larger or smaller charge of unvarying richness, and is capable of easy adjustment by hand while the engine is running,

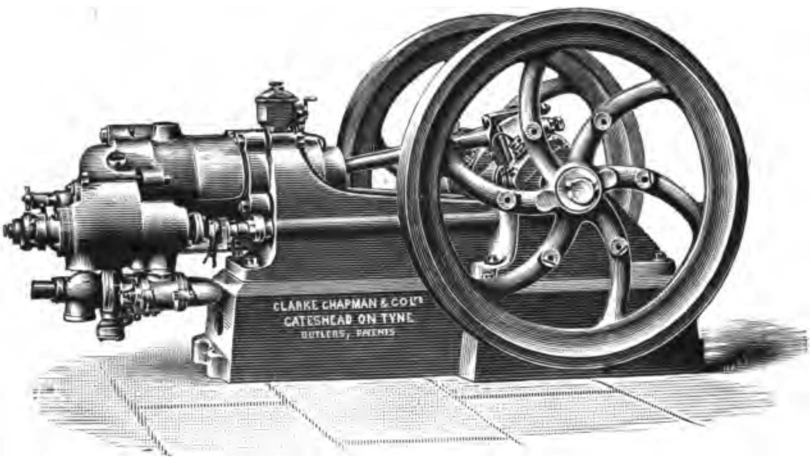


FIG. 53.—CLARKE, CHAPMAN & CO.'S ENGINE

enabling any required speed to be maintained in the manner obtained in ordinary steam engine practice, the governor automatically keeping the engine at that speed. The charge is exploded at the end of the compression stroke by an electric spark from an induction coil excited by a bichromate battery, which is charged about every other day with 1¼ lb. of acid mixture in the form of a damp red paste.

Figs. 56 and 57 are diagrams taken from a 33 B.H.P. engine, and show the remarkable speed obtained with a variation in load from 32 to 5 B.H.P. Fig. 58 is a diagram taken when the engine is running light.

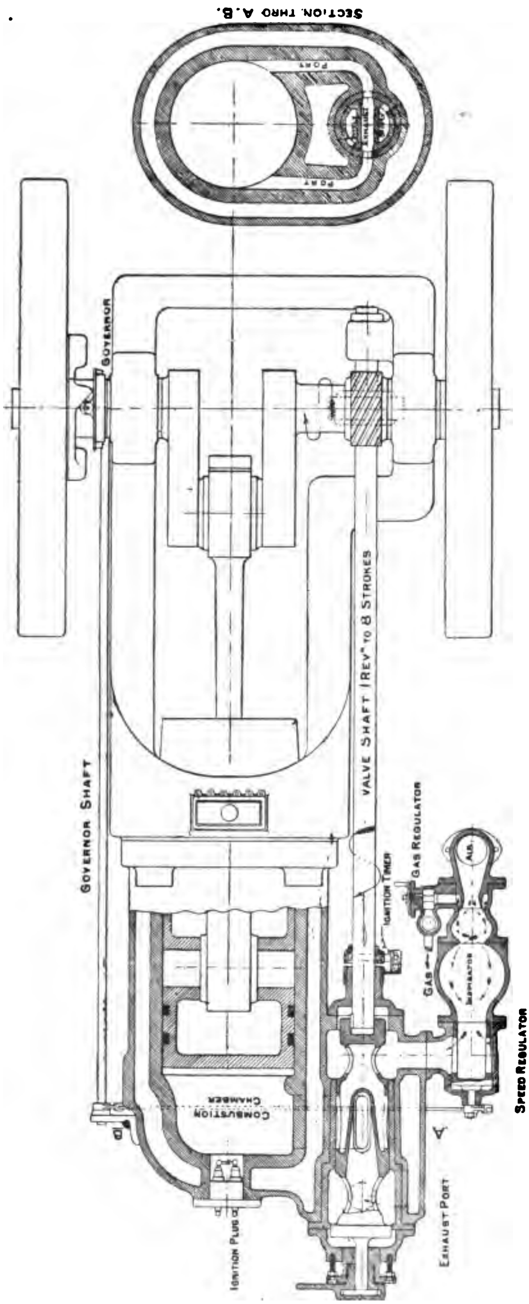


Fig. 55

Fig. 54

Figs. 54, 55.—Clarke, Chapman & Co.'s Engine

The general proportions of this engine are good and the simplicity very marked. There is, however, a strong prejudice against electric ignition; but the makers supply this type

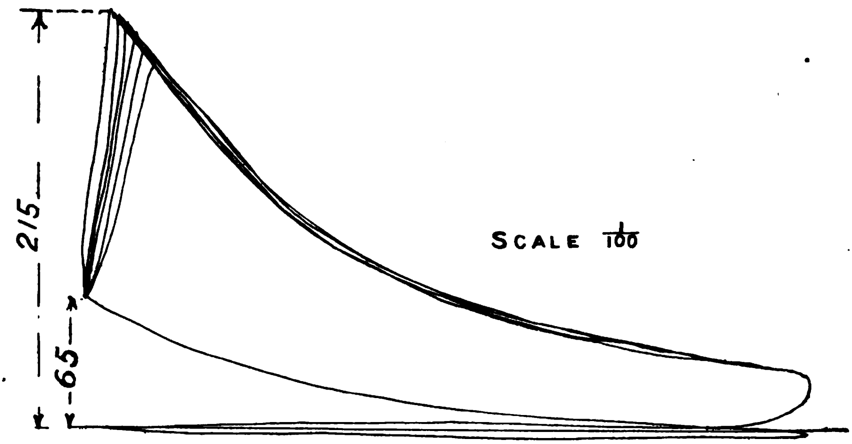


FIG. 56

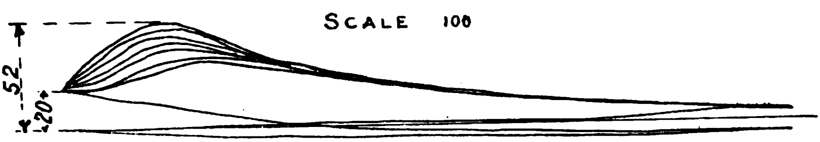


FIG. 57

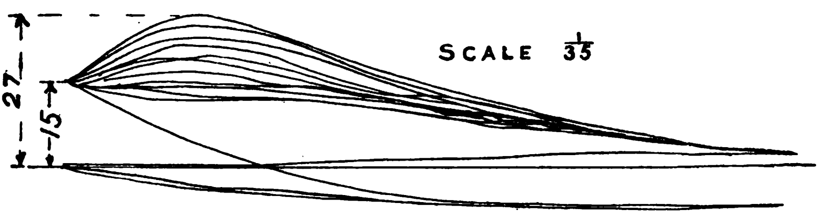


FIG. 58.—MOTOR DIAGRAMS.—CLARKE, CHAPMAN & CO.

of engine with tube ignition, and the charge is sufficiently explosive to be fired by an incandescent tube, so that equally good results can be obtained in this way.

CHAPTER V

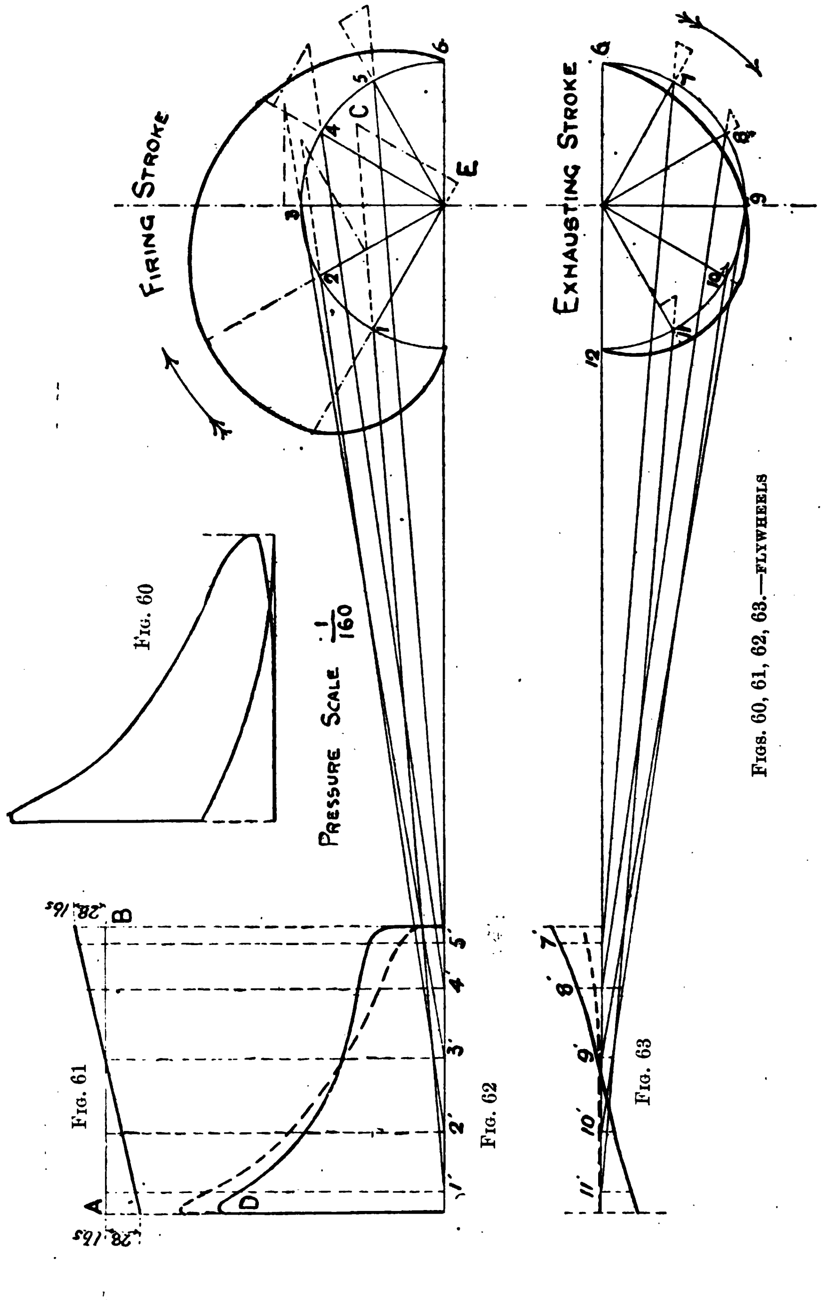
FLYWHEELS

THE object of a flywheel is to reduce the fluctuations in the speed of an engine due to the inequality of power and resistance. In an 'Otto' engine, since the piston turns the crank only half a revolution during the explosion stroke, the energy stored in the flywheel must be considerable to keep up the rotation during the negative strokes, with the result that very heavy ones must of necessity be used.

The superiority of the graphical over the analytical methods for determining the weight of a flywheel is generally acknowledged, and deals with all the variable functions entering into the question with a simplicity, clearness, and accuracy perfectly adequate to the demands of practice. Yet, however advantageous its application, an amount of labour is involved not always at the disposal of the designer.

The first step to be taken in fixing the weight of any flywheel for a given engine is to ascertain the tangential pressure and turning effort on the crank pin, taking into account the effect of the reciprocating parts, which may be found as follows. Fig. 60 is an indicator diagram taken from an engine having a cylinder 19 inches in diameter and a stroke of 30 inches, running at 120 revolutions per minute. The weight of the piston and gudgeon in this engine is 546 lbs., the connecting rod = 786 lbs., making a total weight of the reciprocating parts of 1,332 lbs. This indicator diagram must be corrected, as the reciprocating parts—viz. the piston and connecting rod—are in a state of rest at the commencement of the stroke, and power is expended in accelerating or bringing them to the required velocity; then at the end of the stroke the inertia possessed by them must be added to the pressure behind the piston.

Therefore, taking the movement of the piston corresponding

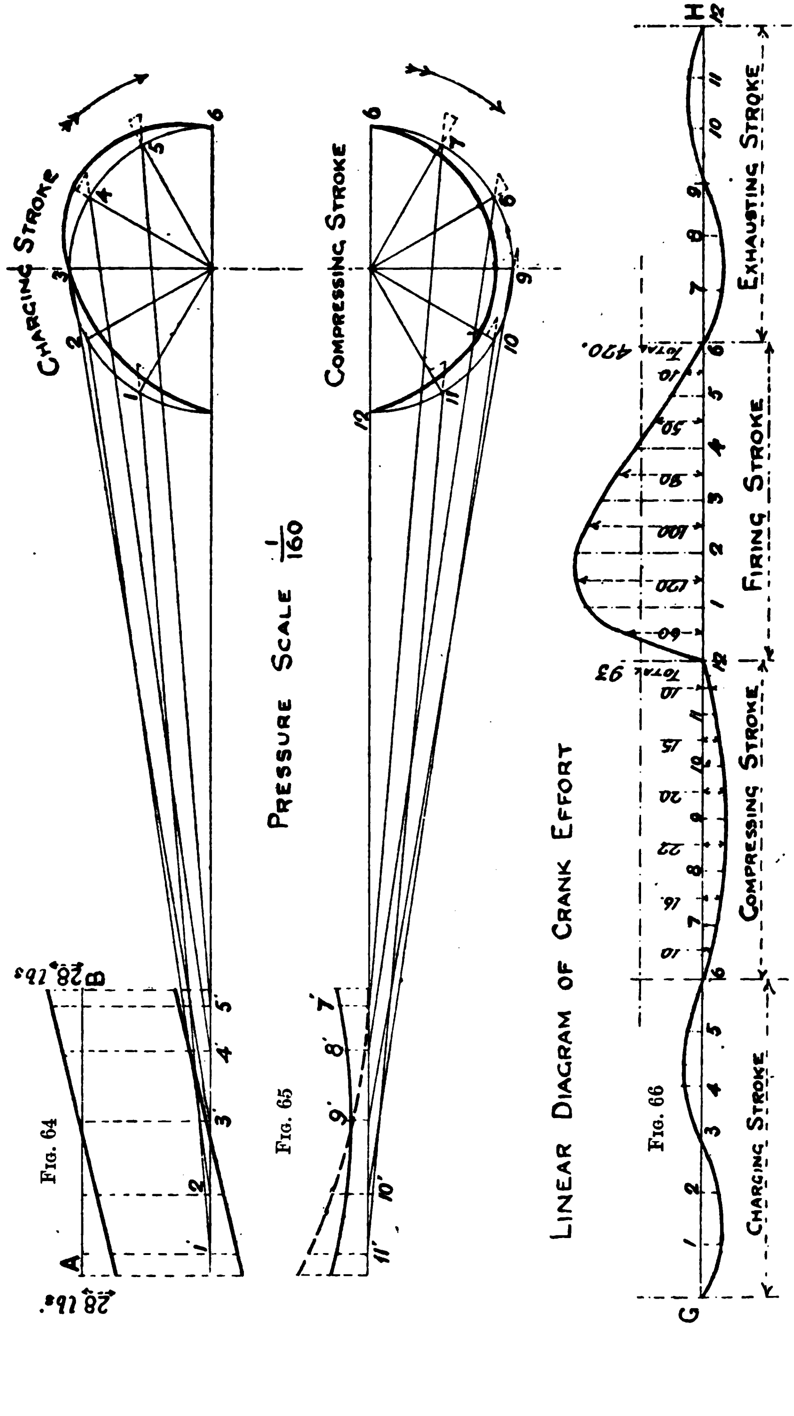


FIGS. 60, 61, 62, 63.—FLYWHEELS

to 1° of turning of the crank, the extent of motion will be the versed sine of an angle of 1° with a radius of 1·25 foot $= \cdot 0001523 \times 1 \cdot 25 = \cdot 00019$ foot in the time of $\frac{1}{360} \times \frac{60}{120}$ $= \frac{1}{720}$ of a second, which is equivalent, as regards the accelerating force required to produce it, to a motion of ·00019 $= \frac{f}{2} \times \left(\frac{1}{720}\right)^2$.

Whence $f = \cdot 00019 \times 518400 \times 2 = 196 \cdot 99$ feet per second, the space passed through, under a uniformly accelerating force, being in proportion to the square of the time; therefore this motion of 196·99 feet per second being 6·1 times the acceleration due to gravity (32·2 feet per second), the force required to impart this velocity amounts to 6·1 times the weight of the reciprocating parts $= 1332 \times 6 \cdot 1 = 8125 \cdot 2$ lbs. = to a pressure of $\frac{8125 \cdot 2}{283 \cdot 5 \text{ (area of piston)}} = 28$ lbs. per square inch, which equals the accelerating and retarding force due to the inertia of the moving parts. Although there is a slight difference in the effect produced at each end of the stroke, owing to the angularity of the connecting rod, it may be neglected for the purpose of this example.

Fig. 61 is a diagram showing this accelerating and retarding force above and below the horizontal centre line A B, superposed for the purpose of correcting the original diagram (fig. 60); by joining these two forces we get a diagram which gives the pressure at any part of the stroke, and by subtracting and adding these pressures to the original diagram (fig. 60) we get the corrected diagram as shown in fig. 62 for the firing stroke, fig. 63 for the exhausting stroke, fig. 64 for the charging stroke, and fig. 65 for the compression stroke. Now take position 1 of crank pin and join 1′, prolonging centre line of connecting rod beyond point 1 to C, making 1 C = 1′ D pressure on piston, and neglecting angularity of connecting rod this equals pressure transmitted to crank pin by connecting rod. This pressure is now resolved into two forces, by drawing a perpendicular to centre line of crank arm to pass through point C; then



FIGS. 64, 65, 66.—FLYWHEELS

C E will be one force acting tangentially to crank, and tending to turn it round, and 1 E will be the other force acting through the crank, resulting in pressure on bearings. We find the tangential forces for the remaining positions of crank, and a curve drawn through these points will give a circumferential diagram showing the turning efforts on the crank pin exerted by pressure on the piston. The same process is repeated for fig. 63, showing the negative and positive pressures on the exhausting stroke, fig. 64 on the charging stroke, and fig. 65 on the compressing stroke.

Fig. 66 shows in a linear diagram the pressures at the various points of the stroke, G H representing the path of the crank pin, the positive pressures being above and the negative ones below the line, showing at a glance how the pressure on the piston is distributed to the crank pin, being diminished or increased as the inertia of the weight of the moving parts is acting with or against it. Thus, commencing with the charging stroke, it is assumed that the charge enters at atmospheric pressure (although in practice this is found to be 1 or 2 lbs. below), so that the pressure on the crank pin is governed altogether by the inertia of the moving parts, as through the first three divisions the energy stored in the flywheel has to be utilised in drawing the piston forward, imparting to the moving parts their required amount of inertia. From the middle of the stroke to the end the work is done by the pressure required to bring the moving parts to a state of rest, and during the compression stroke the effect of the inertia is to make the work done by the flywheel equal at each end of the stroke, and greatest in the middle, whilst on the firing stroke the inertia has the effect of reducing the pressure of explosion on the crank pin at its commencement, and does not reach its maximum until about a quarter of the stroke has been completed, when the pressure gradually decreases until the exhausting stroke commences, when the energy stored by the flywheel drives the piston back, expelling the products of combustion; and on reaching the middle of the stroke the energy stored in the moving parts again comes into play, so that no power is lost by this inertia, as the amount absorbed at one part of the stroke is given out at the other.

The mean of the pressures contained in the six divisions of the compression stroke (fig. 60) is 15 lbs. pressure on the crank pin per square inch of piston area, which work has to be done by the stored-up energy in the flywheel. In the same way the pressure for the firing stroke will be $\frac{420}{6} = 70$ lbs. per square inch of piston area on crank pin; subtracting the negative mean tangential pressure during the compression stroke from the positive mean tangential pressure during the firing stroke, $= 70 - 15 = 55$ lbs. which mean pressure, having to be distributed between the number of strokes in a complete cycle, gives $\frac{55}{4} = 13{\cdot}75$ lbs., and this deducted from that of the firing stroke, viz. $70 - 13{\cdot}75 = 56{\cdot}25$ lbs. = the excess tangential pressure obtained during the firing stroke. The work supplied by a flywheel during its retardation $= \frac{W}{2g}$ (V^2 max. $- V^2$ min.), where W = weight in lbs., g = acceleration of gravity, V maximum = the highest, and V minimum = the reduced velocity, in feet per second. The variation in speed should not exceed 5 per cent. for commercial engines, and where extreme steadiness of running is required the variation should not exceed 2 per cent. With 5 per cent. variation (that is, from $1{\cdot}025$ to $\cdot975$ of the mean or reputed speed) $V = (V \text{ max.}^2 - V \text{ min.}^2) = \cdot1\, V^2$, hence the work of retardation of the wheel $= \frac{\cdot1\, W V^2}{2\, g}$ foot-lb., and the work to be stored up in the flywheel $= 56{\cdot}25 \times 3{\cdot}9 \times 283{\cdot}5$ (square inches) = 62,171 foot-lbs., where $56{\cdot}25$ equals the excess of tangential pressure during the firing stroke in pounds per square inch of piston area, $3{\cdot}9$ equals half the circumference of the crank pin circle in feet, and $283{\cdot}5$ square inches equals the piston area.

Assuming the diameter of the flywheel to be 10 feet, the mean velocity of rim $= \frac{10 \times 3{\cdot}1416 \times 120 \text{ revolutions}}{60} = 62{\cdot}8$ feet per second = V. $V^2 = 3943$.

We can now resolve the equation into

$$\cdot 1 \ \frac{W \times V^2}{2g} = 62{,}171 \text{ foot-lbs.}$$

$$\frac{1}{10} \times \frac{W}{1} \times \frac{62 \cdot 8^2}{2 \times 32} = 62171$$

$$\therefore W = \frac{62171}{1} \times \frac{640}{3943} = \frac{39789440}{3943}$$

$$= 10093 = 4 \text{ tons } 10 \text{ cwts.}$$

the weight of flywheel required for the above engine.

For approximate weight of flywheels the above diagrams and formulæ may be taken as a standard, as all gas engine indicator cards are much the same.

The different methods by which the flywheels are keyed to the crank shaft are illustrated in figs. 67 and 68. Fig. 68 is the method used for small and medium sized engines. But for larger sized engines two keys are generally fitted, as shown in fig. 67, one of which is a saddle key.

Fig. 69 shows a special method of keying flywheels on large engines which was designed by Mr. S. Quipp, one of the staff of Robey & Co., and differs from fig. 67 in that, instead of a saddle key, a special form is used, sunk deep in the flywheel at one side, and deep into the shaft at the opposite side, the direction of running determining the deep side, the shallow side in the shaft always leading in the direction in which the engine is running. This key drives as a strut in the manner indicated by the arrows, the bearing surface in proportion to cross section being considerably increased, taking all the driving strain due to the pressure of the explosion, and effectually resisting the shock due to the starting impulse, which in all pressure starters is very great, the heavy flywheel having to get up the required velocity due to the force of this impulse almost instantaneously, and the inertia of the flywheel acting against this impulse causes a very severe strain on the sides of the key beds in both shaft and flywheel, the result being that it soon becomes loose when a single key is used. Flywheels over 7 feet in diameter should be cast in halves, as the greater frictional grip obtained by the bolts assists the keys in a very efficient manner.

Until recently the practice of gas engine makers was to fit

two flywheels to each engine, each wheel being but half the weight given by the foregoing formulæ. Although this practice is still followed in small engines the tendency is towards the use

FIG. 67

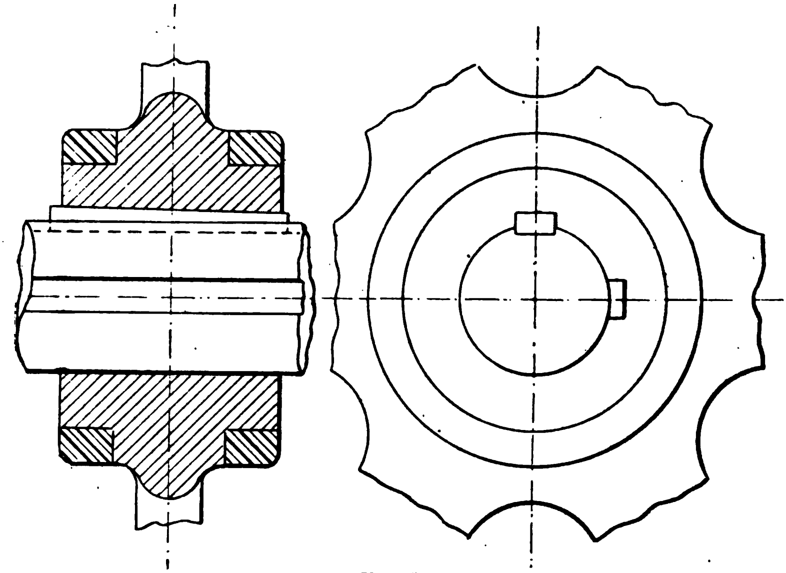
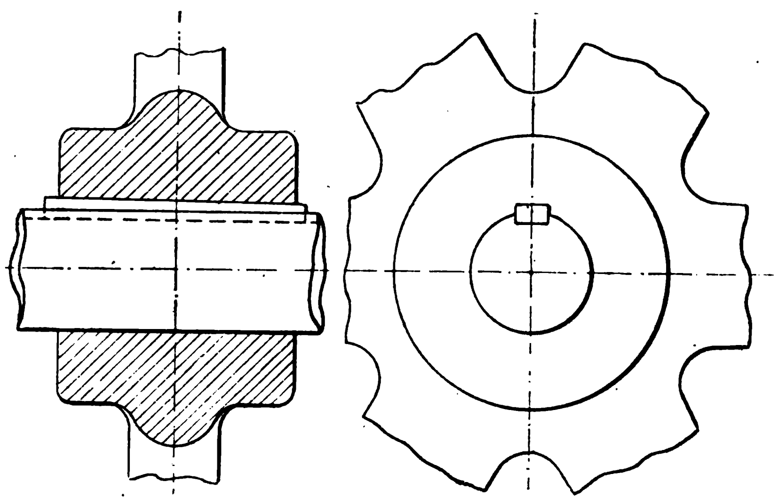


FIG. 68



FIGS. 67, 68.—FLYWHEELS

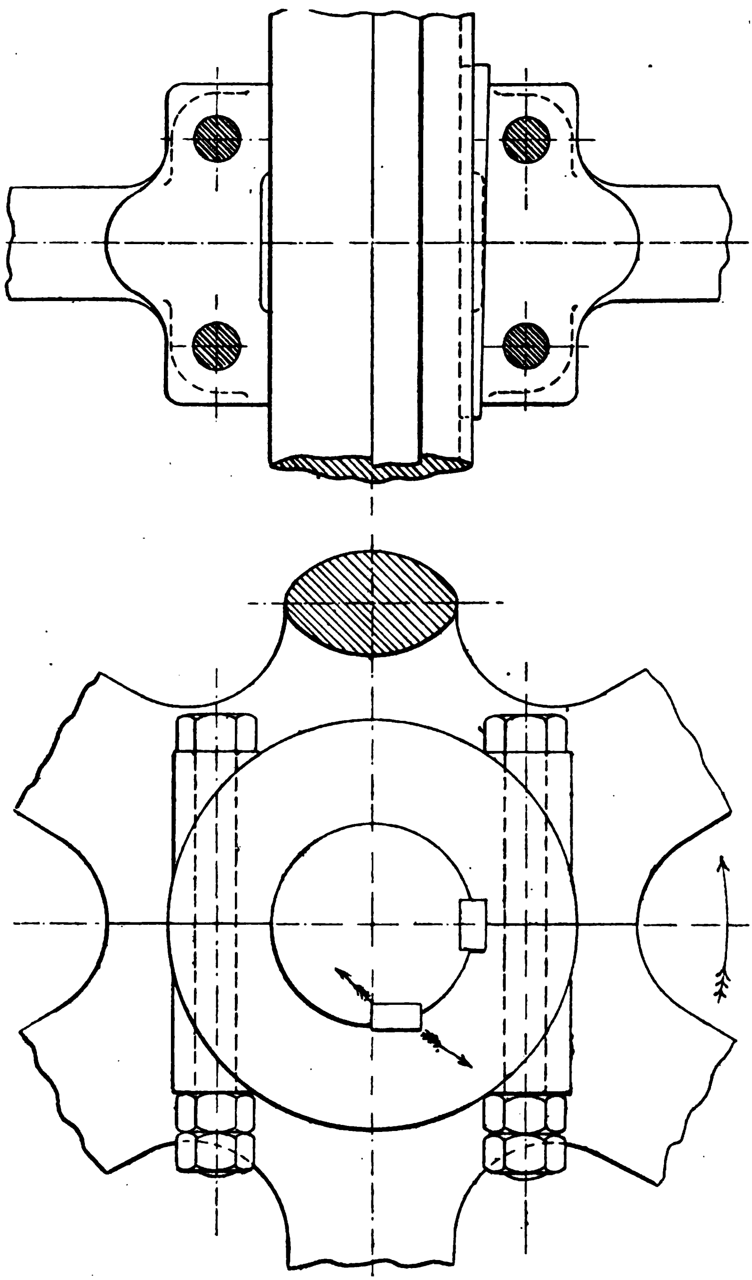


FIG. 69.—FLYWHEELS

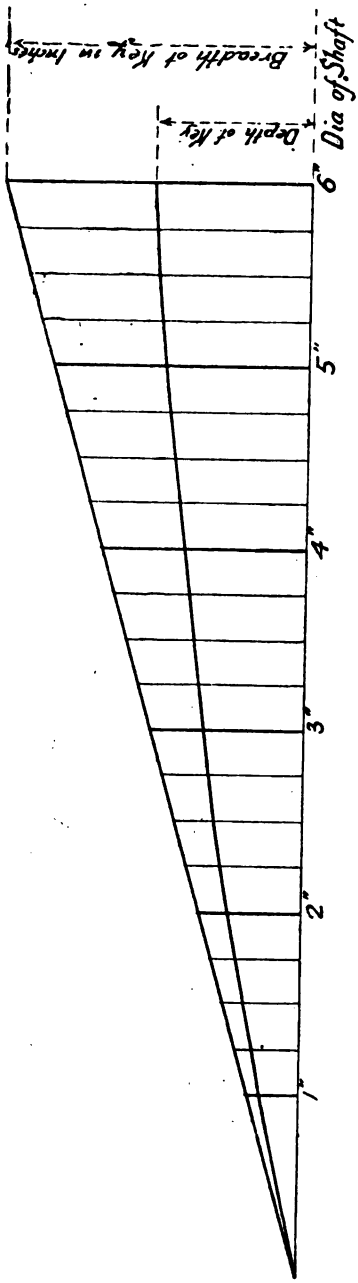


Fig. 70·—Flywheel keys

of one flywheel only; and in engines giving over 40 E.H.P. the crank shaft should be enlarged where the flywheel is fitted, which enlargement may be continued sufficiently far to take the driving pulley. There should be a journal and outer bearing at the end of the crank shaft with the flywheel and pulley between it and the engine crank neck. This makes a much better arrangement than taking the whole power of the engine off at a distance from the bearing by means of an overhung crank shaft. In large engines, where the crank shaft is enlarged, say, a quarter of an inch for every inch diameter of engine crank neck bearing, and where the systems shown in fig. 69 are used, the size of the key may be as follows: Breadth of key = diameter of enlarged shaft ÷ 4, depth of key. = half the breadth, and the depth of key-way in shaft may be half the depth of key. But where there is no enlargement of shaft then the keys should be larger, especially in their depth.

Fig. 70 is a diagram giving the sizes of the keys as generally used.

The following formulæ for flywheels of single-acting 'Otto' cycle engines is based on the practical experience gained by Mr. F. W. Lanchester with over 500 engines, so far as the constants are concerned.

It is assumed for purposes of convenience that flywheels of different sizes are geometrically proportional in their various parts.

Let W = weight of wheel in cwts.
D = outside diameter of rim in feet.
V = volume in cubic feet swept by piston.
P = mean effective pressure of working stroke.
C = constant.
R = revolutions per minute.

$$\text{Then } W = \frac{1}{D^2} \times \frac{1}{R^2} \times V \times P.$$

$$\text{That is, } W = \frac{V\,P}{D^2\,R^2}\,C;$$

$$\text{or } \frac{D^2\,R^2\,W}{V\,P} = C.$$

Value of 'C' from Practice.—For engines for ordinary purposes, C = 125; for engines for electric lighting purposes, C = 250; Messrs. Crossley, for electric lighting engines, make C = 400.

In practice the constants 125 to 250 are sufficient when the engine is fitted with good governor gear. Unfortunately for the efficiency of many engines flywheels are used which are too heavy when the governor is in action to respond quickly to the governor control, which is a more important factor than storing energy in the flywheel when steady running is required. But as this result is difficult to obtain without very 'close' governing, many makers hide their inability by laying great stress on the heavy flywheels fitted to their engines.

CHAPTER VI

CRANK SHAFTS

In the various engines dealt with from page to page attention has been drawn to the types of crank shafts used on them, Crossley's and Robey's using upon all sizes the form known as the 'slab' crank, and the other makers having arbitrarily and with no uniformity as to size of engine, adopted both this and the 'bent' forms; and it would appear that in many cases the makers seem at a loss to know how to determine the sizes, if the divergencies from any possible formulæ in their own manufactures can be taken as evidence.

It is necessary in proportioning the crank shaft to take into account the combined strains to which it is subjected, one of which is due to the twisting action caused by the pressure acting on the crank pin, and the other to bending owing to the distance of centre of crank pin from centre of bearings.

In some formulæ for determining the size of crank shafts it is given that the latter force may be neglected and the diameter found for the twisting action only. By this rule the diameter of the shaft will be $= \sqrt[3]{\frac{s \times l}{120}}$ for steel, where s = load on piston (area of cylinder $\times$ maximum pressure of explosion), l = length of stroke in feet; but this rule is only approximate, as the bending moment is a very considerable item, and is well shown by the following graphic method.

Suppose an engine has a cylinder of 19 inches bore $\times$ 30 inches stroke, with a maximum tangential force of 120 lbs. per square inch (as found in figs. 61 and 62), which may be taken as a constant in all engines using the same compression, a maximum pressure of 34,000 lbs. is exerted on the crank pin. By plotting out the centre line of the crank shaft A B (see fig. 71), together with centre line of crank pin C F G and centre lines of crank shaft bearings A and B, projecting these down to the horizontal line a b c, continue point c downwards, and set

off $c\ d$ = maximum force on crank pin, viz. 15 tons. And on a line projected downwards through a, representing the centre

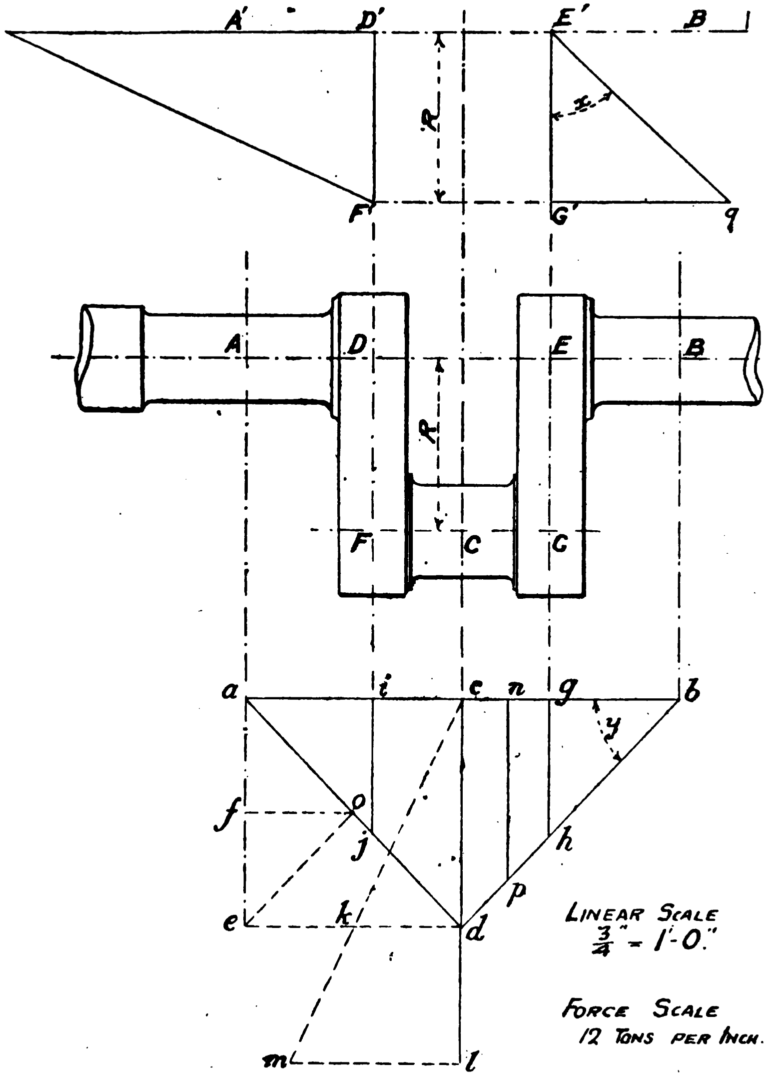


FIG 71.—CRANK SHAFTS

line of one main bearing, set off $a\ e = c\ d$, and from b, which represents the centre line of the other main bearing, draw $b\ d$,

join $a\ d$, and from e draw a line $e\ o$ parallel to $b\ d$, cutting line $a\ d$ at the point o. From o draw $o\ f$ perpendicular to $a\ e$, when $e\ f$ will equal the load on the bearing B, and $f\ a$, the load on the bearing A, $o\ f$ being the polar distance for the bending moment diagram a, b, d. In this engine; the power being all taken from the side A D of the crank shaft, the side B F has nothing to drive but the cross shaft of the engine, therefore **the shaft B E** is subject only to a bending strain, as shown by the right-hand side of bending moment diagram g, h, b.

The shaft A D is subject to a bending strain, as shown by the left-hand side of the bending moment diagram a, i, j, and to torsion due to the force on the crank pin—viz. 15 tons × radius of crank. Make $d\ k$ parallel to $c\ a$ and = polar distance $o\ f$, and draw a line through $c\ k$, which line continue through k; now draw line $l\ m$ = radius of crank and parallel to $d\ k$. Then $c\ l$ = 24 tons × the polar distance $o\ f$ in feet $= 24 \times \frac{9 \cdot 5}{12} = 19$ foot-tons, the required torsion moment, and $i\ j$ = 9 tons × the polar distance in feet $= 9 \times \frac{9 \cdot 5}{12}$ = 7·1 foot-tons, the maximum bending moment to which the shaft A D is subjected. Combining these into an equivalent torsion moment by the following rule:

$$\text{E. T. M} = \text{equivalent twisting moment}$$
$$= \text{M} + \sqrt{\text{M}^2 + \text{T}^2}$$
$$\text{in which M.} = \text{maximum bending moment}$$
$$\text{and T.} = \text{,,} \quad \text{torsion} \quad \text{,,}$$
$$\therefore \text{E. T. M.} = 7 \cdot 1 + \sqrt{7 \cdot 1^2 + 19^2} = 27 \cdot 37 \text{ foot-tons}$$

the diameter of the crank shaft.

$$= \sqrt[3]{\frac{\text{E. T. M. in lbs.}}{140 \text{ (safe moment for steel)}}}.$$

In this example the diameter of crank shaft $= \sqrt{\frac{61308}{140}}$ $= \sqrt[3]{437} = 7\frac{5}{8}$ inches. The above moment for steel gives a factor of safety of 10, and is based upon a bar 1 inch in diameter breaking with 1,400 lbs. at the end of a lever 1 foot long. **The crank pin** F, C, G is subject to bending, as shown in the diagram

i, j, d, h, g (fig. 71), and also to torsion due to the force *e f* acting at B with radius of crank. Make *b n* = radius of crank, and from *n* draw a line perpendicular to *b n* cutting *b d* in *p*; then *n, p* $= 12$ tons $\times$ the polar distance in feet $= 12 \times \frac{9 \cdot 5}{12} = 9 \cdot 5$ foot-tons, which equals the required torsional moment, and *c d* = 15 tons $\times$ the polar distance in feet $= 15 \times \frac{9 \cdot 5}{12} = 11 \cdot 7$ foot-tons, which equals the maximum bending moment to which the crank pin is subjected.

Combine these two into an equivalent twisting moment.

E. T. M. $= \text{M.} + \sqrt{\text{M}^2 + \text{T}^2} = 11 \cdot 7 + \sqrt{11 \cdot 7^2 + 9 \cdot 5^2}$ $= 26 \cdot 8$ foot-tons, and the diameter of crank pin

$$= \sqrt[3]{\frac{\text{E. T. M. (in lbs.)}}{140 \text{ (safe moment for steel)}}}.$$

In this example the diameter of crank pin

$$= \sqrt[3]{\frac{60032}{}} = \sqrt[3]{430} = 7\tfrac{9}{16} \text{ inches.}$$

In practice, however, the crank pin is never made smaller than the diameter of the crank neck, but generally larger (a good proportion is one-eighth of itself larger), and its length is determined by the maximum working pressure to which it is advisable to subject it so as to eliminate any fear of heating during long runs. This pressure should not exceed 600 lbs. per square inch of crank pin bearing surface, and is best taken as 500 lbs.

The maximum tangential pressure on crank pin being 34,000 lbs., and dividing this by 500 gives 68 square inches as the required area of bearing surface.

The diameter of crank neck being $7\frac{1}{2}$ inches, and making the diameter of pin one-eighth larger we have $8\frac{1}{4}$ inches for its diameter; and as the net bearing surface of a journal equals one-third of its circumference $\times$ its length, or its diameter $\times$ the length,

$\therefore$ The length of the crank pin will be $\frac{68}{8 \cdot 25} = 8 \cdot 25$ inches.

The crank arm E G is subject to bending, due to the force *e f* acting at E, for which the bending moment diagram is found

by making the angle x at E′ = the angle y at b, then G′ q = the maximum bending strain; and to torsion due to the same force acting with the leverage E G and for which amount = $g\ h$. The strains in this arm are small, and are consequently neglected in proportioning the size of the crank arm, the strength being the same as the crank arm D F.

The crank arm D F is subject to bending due to the maximum tangential pressure acting at E, which equals the force $c\ l$ = D′ r = 24 tons × polar distance in feet $= 24 \times \frac{9 \cdot 5}{12} = 19$ foot-tons = the maximum bending moment; and also to torsion, due to the force $a\ f$ acting with the leverage A D, which equals $i\ j$ = 9 tons × polar distance in feet $= 9 \times \frac{9 \cdot 5}{12} = 7 \cdot 1$ foot-tons, the required torsional moment. Combine these two into an equivalent twisting moment. E.T.M. $= M. + \sqrt{M^2 + T^2} = 19 + \sqrt{19^2 + 7 \cdot 1^2} = 39 \cdot 3$ foot-tons.

To find the size of the crank arm assume it to be a cantilever fixed at one end and loaded at the other, the equivalent bending moment taken $= \frac{\text{equivalent twisting moment}}{2}$. In this case $\frac{39 \cdot 3}{2} = 19 \cdot 65$ foot-tons = 44016 foot-lbs.

A 1-inch square steel bar 1 foot long, fixed at one end and loaded at the other, will break with a maximum bending moment of 1,200 foot-lbs., or with a factor of safety of 10 = 120 foot-lbs. safe bending moment.

The safe bending moment of any bar will equal $b \times d^2 \times 120$ ft.-lbs. where b equals breadth and d equals depth, therefore $\frac{\text{bending moment}}{120} = b \times d^2$.

By assuming one dimension for crank arm, the other may readily be found. Thus, assuming the breadth of crank web, which is often made ·8 of the diameter of crank shaft, then $7 \cdot 5 \times \cdot 8 = 6$ inches equals breadth of crank arm; the other dimension will be $\frac{44016}{6^2 + 120} = \frac{44016}{4320} = 10 \cdot 1$ inches.

In the above example the flywheel and driving pulley are on one side of the engine, with the outer end of crank shaft carried by a third bearing, and, strictly speaking, the bending moment diagram should also be drawn for weight of flywheel, &c.; but in most cases this moment will be less than the combined equivalent twisting moment as found for shaft A D, so that the diameter of the crank shaft as found from the latter will be more than ample to cover the extra weight of flywheel and driving pulley,

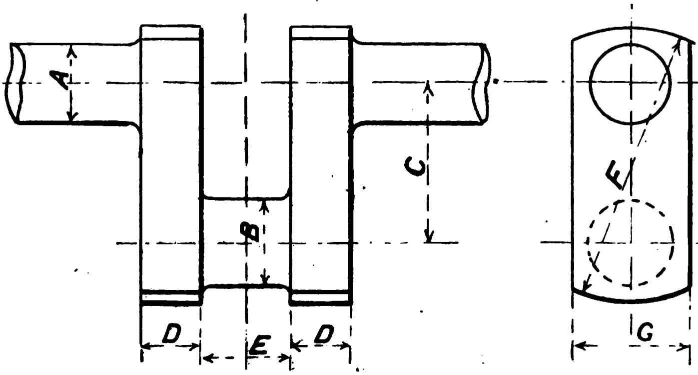


FIG. 72

Cylinder Diam.	Cylinder Stroke	A	B	C in.	D	E	F ft.	F in.	G
5	8	$1\frac{3}{4}$	$1\frac{7}{8}$	4	$1\frac{1}{2}$	2		$6\frac{1}{2}$	$2\frac{1}{2}$
$5\frac{3}{4}$	9	$2\frac{1}{4}$	3	$4\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{5}{8}$		$8\frac{1}{2}$	$3\frac{1}{2}$
$7\frac{1}{2}$	11	$2\frac{3}{4}$	$3\frac{1}{4}$	$5\frac{1}{2}$	$2\frac{3}{8}$	3		$9\frac{1}{2}$	$4\frac{1}{2}$
$8\frac{1}{2}$	15	$3\frac{1}{4}$	4	$7\frac{1}{2}$	$2\frac{7}{8}$	$3\frac{1}{2}$		$12\frac{1}{2}$	5
$8\frac{1}{2}$	18	$3\frac{1}{4}$	4	9	3	$3\frac{1}{4}$	1	2	5
$9\frac{1}{2}$	18	$3\frac{1}{2}$	$4\frac{1}{4}$	9	$3\frac{3}{8}$	$3\frac{1}{4}$	1	3	$5\frac{1}{2}$
12	18	$4\frac{1}{4}$	$4\frac{3}{4}$	9	$3\frac{3}{4}$	$4\frac{1}{2}$	1	$3\frac{1}{4}$	$6\frac{1}{4}$
$11\frac{1}{2}$	21	$4\frac{1}{4}$	$4\frac{3}{4}$	$10\frac{1}{2}$	4	$3\frac{1}{2}$	1	$3\frac{1}{2}$	$6\frac{1}{2}$
14	21	$5\frac{1}{2}$	$5\frac{3}{8}$	$10\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{4}$	1	5	$8\frac{1}{2}$
17	24	7	8	12	$5\frac{3}{4}$	$7\frac{1}{2}$	1	$10\frac{1}{2}$	10
19	30	$7\frac{1}{2}$	8	13	6	9	2	2	11

FIG. 72.—SLAB CRANKS

also in engines of this class the crank shaft is enlarged between the engine main bearing and outer bearing to compensate for loss of section owing to the cutting of key bed. This enlargement may be made $\frac{1}{4}$ inch for every inch in diameter of crank shaft. (See Flywheels, page 72.)

G

With fig. 72 is given a table of sizes of crank shafts, of the slab form, from actual practice of some of the best makers, and with fig. 73 a table of sizes for the 'bent' forms.

FIG. 73

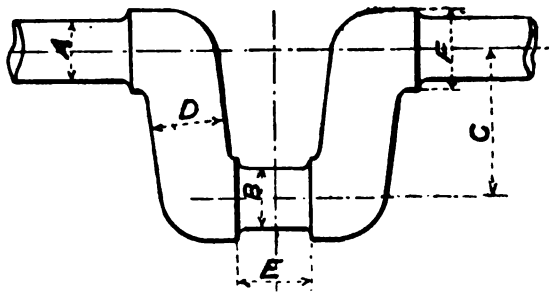
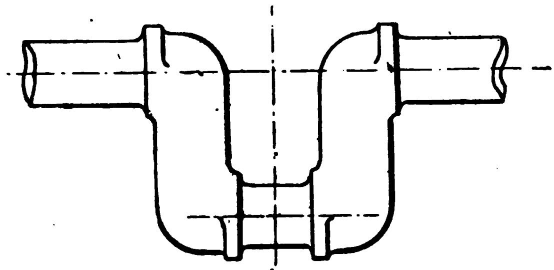


FIG. 74



Cylinder		A	B	C	D	E	F
Diam.	Stroke						
5	10	1⅞	1⅞	5	2¼	—	2¼
6	12	2	2½	6	3	—	3
8½	16	3¼	3¼	8	3¾	—	3¾
10	18	4	4	9	4½	5	4½
12	20	5	5	10	5½	5½	5½

FIGS. 73, 74.—BENT CRANKS

Balanced Crank

When dealing with the Robey gas engines mention was made of the method by which the reciprocating parts were balanced, by means of counter weights strapped to the webs. The method of building up and fixing them is clearly shown on figs. 75 and 76.

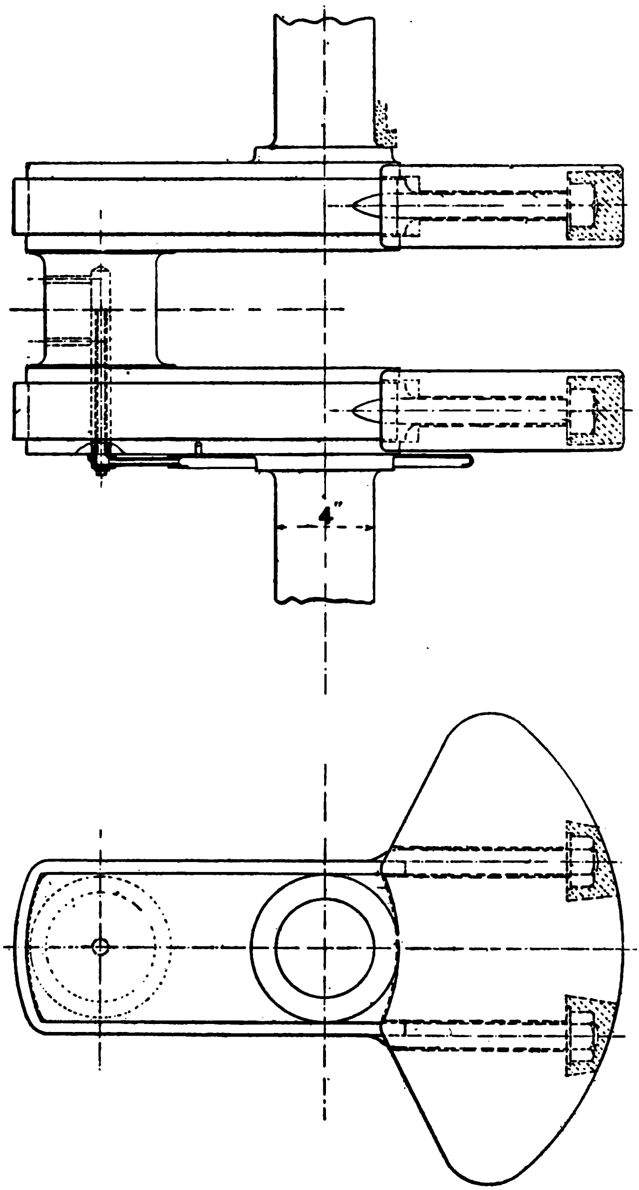


FIG. 76

FIG. 75

FIGS. 75, 76.—ROBEY BALANCE CRANK

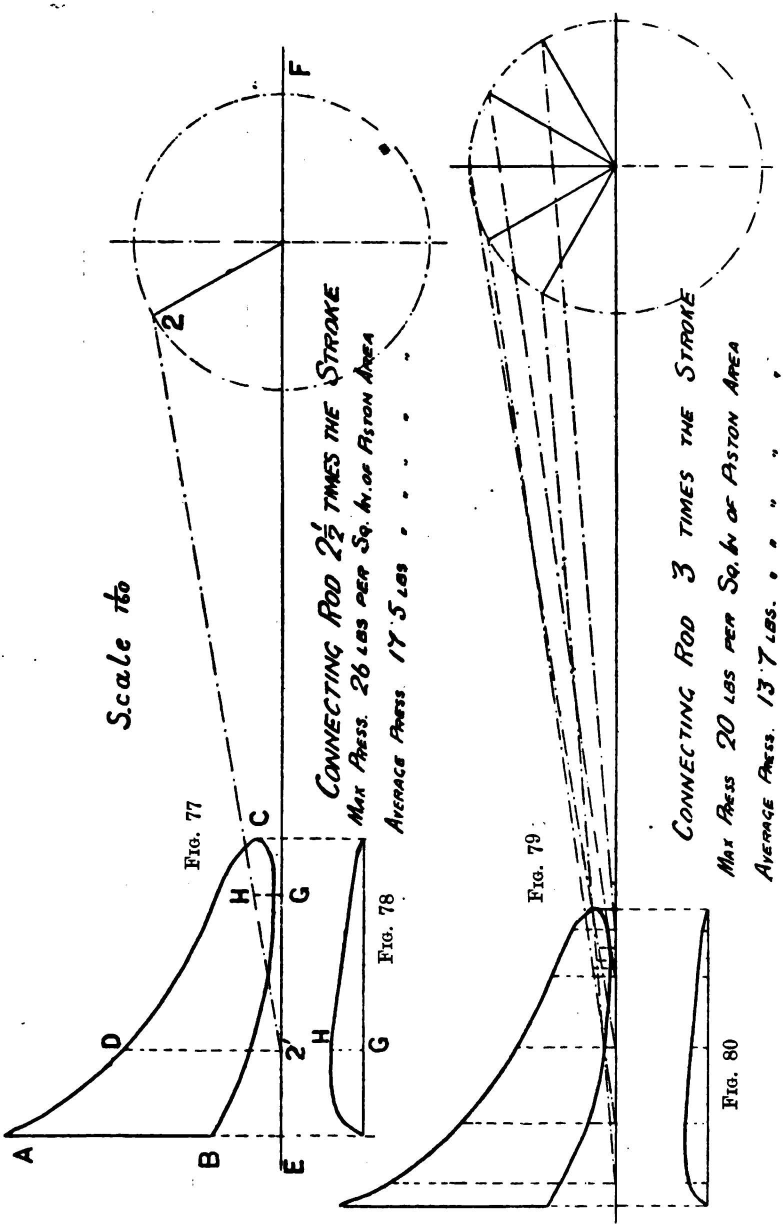
CHAPTER VII

PISTONS

THE general practice with gas engine makers is to dispense with slide bars and crosshead as used in the steam engine, and to transmit the force from the piston direct to the connecting rod, the former being made of trunk form, very long, and usually about double its diameter. The gudgeon pin is at or about the centre of its length. The piston should be of such a length that the pressure due to the angularity of the connecting rod—usually termed the pressure on the slide bars—shall not be excessive. This pressure should not exceed 20 lbs. per square inch of piston circumferential rubbing surface, which is usually taken as the diameter × its length. A simple graphic method of finding this pressure from indicator diagrams is as follows.

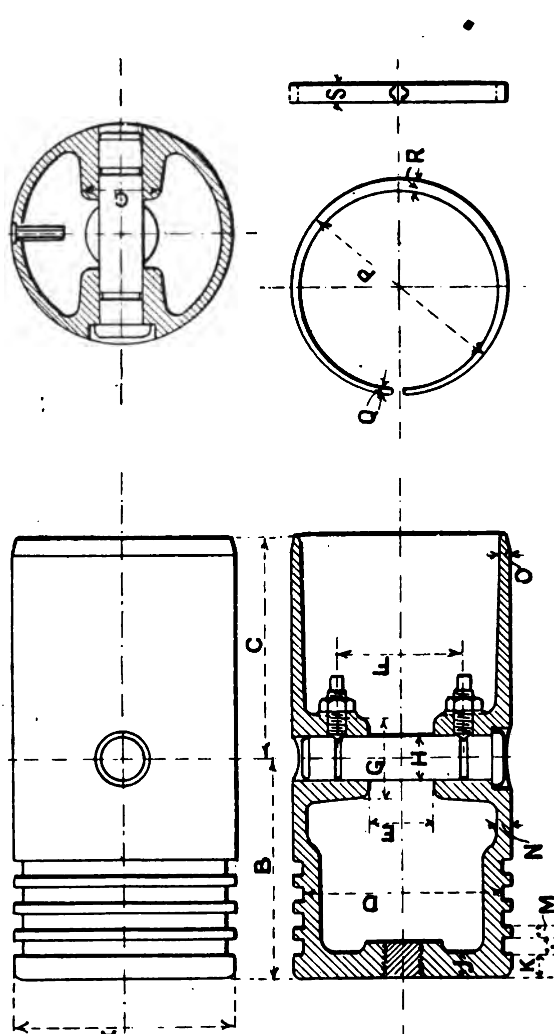
In fig. 77, A B C is the indicator diagram taken from an engine having a cylinder 18 inches in diameter and a stroke of 24 inches, and the length of the connecting rod is 2·5 times the length of the stroke. The length of diagram E C represents the stroke of the piston. Now draw the length of connecting rod and path of crank pin to same scale, divide the crank pin circle into any number of parts, and draw the position of crank to correspond. Assume position 2 to be one of these, and with radius equal to length of connecting rod mark off position of piston on its path, as at 2′. Now if the distance 2′ to D, which represents the pressure on the piston at the point 2′, be marked off on horizontal line E F by drawing a vertical line from point G cutting the centre line of connecting rod at H, then G H will be the vertical pressure on the slide bar at position 2 of crank. In the same way the pressures may be found at any other position, and the results plotted to give a diagram as at fig. 78.

The maximum pressure at G H = 26 lbs. per square inch of piston area, and if the diameter of the piston is 18 inches = 254 square inches, this area × 26 = 6604 lbs. maximum



Figs. 77, 78, 79, 80.—Graphic method of finding pressure on slide bars

pressure on slide bars. Suppose the length of the piston is 36 inches, then the total rubbing surface will be D × L = 18 × 36 = 648 square inches. Therefore $\frac{6604}{648} = 10{\cdot}1$ lbs. per



Max. B.H.P.	Cylin Diam.	Cylin Stroke	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	Q	R	S	No. of Rings
$3\frac{3}{4}$	6	9	6	$5\frac{3}{4}$	$5\frac{3}{4}$	$5\frac{3}{8}$	$2\frac{1}{8}$	$3\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{3}{8}$	$\frac{5}{8}$	1	$\frac{15}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{16}$	$6\frac{1}{16}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{5}{16}$	4
9	8	2	8	8	8	$7\frac{3}{8}$	$2\frac{3}{4}$	5	3	$1\frac{3}{4}$	1	1	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{1}{4}$	$8\frac{1}{16}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{8}$	5
35	13		13	13	13	$12\frac{1}{8}$	$4\frac{3}{4}$	$7\frac{1}{2}$	$5\frac{1}{2}$	$3\frac{1}{2}$	1	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{4}$	$13\frac{1}{8}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	6

All Dimensions in Inches

FIG. 81.—PISTONS

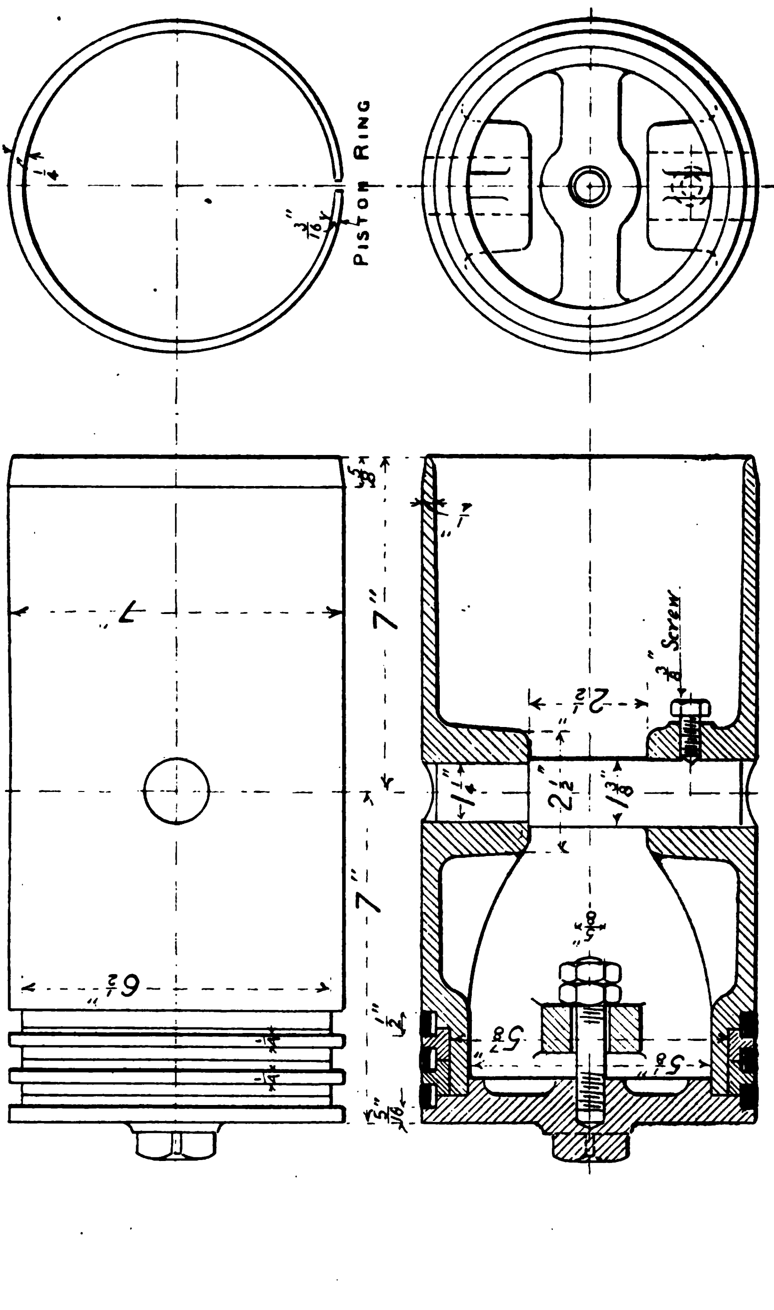


FIG. 82.—PISTONS

square inch pressure on slide bars due to thrust of connecting rod, inclined as in fig. 77. Obviously it is not necessary to use slide bars on engines having a well-proportioned piston.

Figs. 79 and 80 are diagrams from the same size of engine, having a connecting rod of three times the length of stroke, and show the diminution of pressure on slide bar as the length of the connecting rod is increased.

Fig. 81 is a table of sizes taken from actual practice, and fig. 82 is a form of piston used by several makers.

CHAPTER VIII

CONNECTING RODS

THE connecting rods, subjected as they are to a compressive stress, are usually made of mild steel, and the distance between centres varies from 2·25 to 3 times the length of the stroke. The strength of any given rod may be found from the following formulæ:

r = Ratio of length to diameter

$$W = \frac{30}{1 + \frac{r^2}{1400}}$$

Where W = breaking load in tons per square inch.

Example 13 inches × 21 inches stroke engine, centres of connecting rod 63 inches, diameter at the middle of rod 3 inches, giving a ratio of 21 to 1.

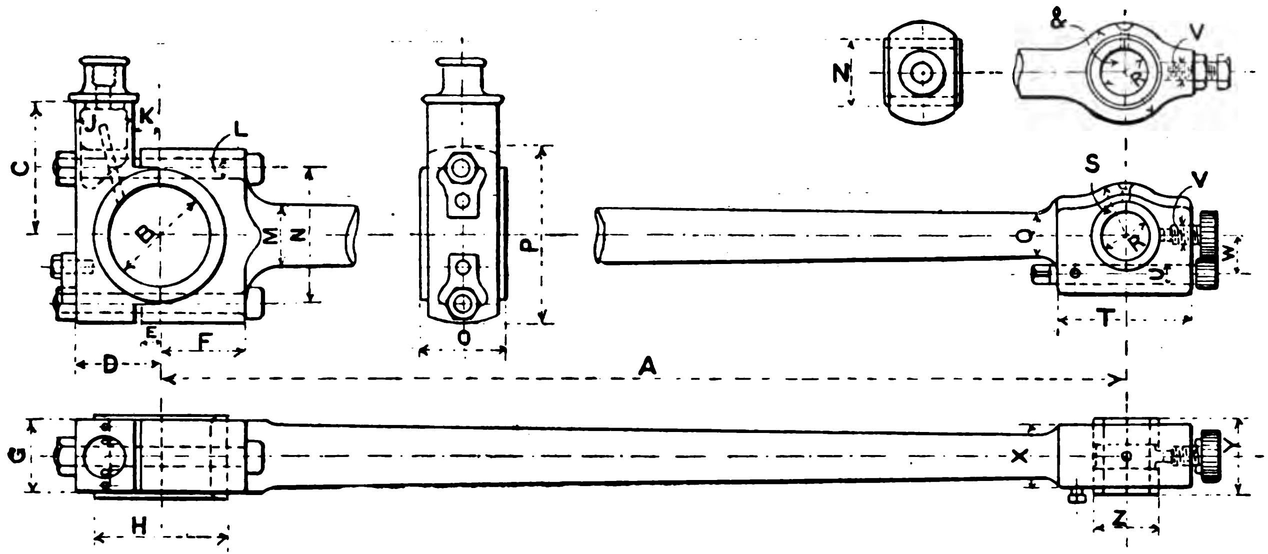
$$W = \frac{30}{1 + \frac{21^2}{1400}} = \frac{30}{1} \times \frac{1400}{1841}$$

$= 23$ tons per square inch of sectional area.

The area of the diameter in the centre = 7 square inches, the breaking load for the rod will be 23 × 7 = 161 tons.

A factor of safety of from 10 to 12 should be allowed.

Fig. 83 is a type of connecting rod very largely used on all sizes of engines with satisfactory results. The large end of the rod proper is carried beyond its centre line, bored to receive a



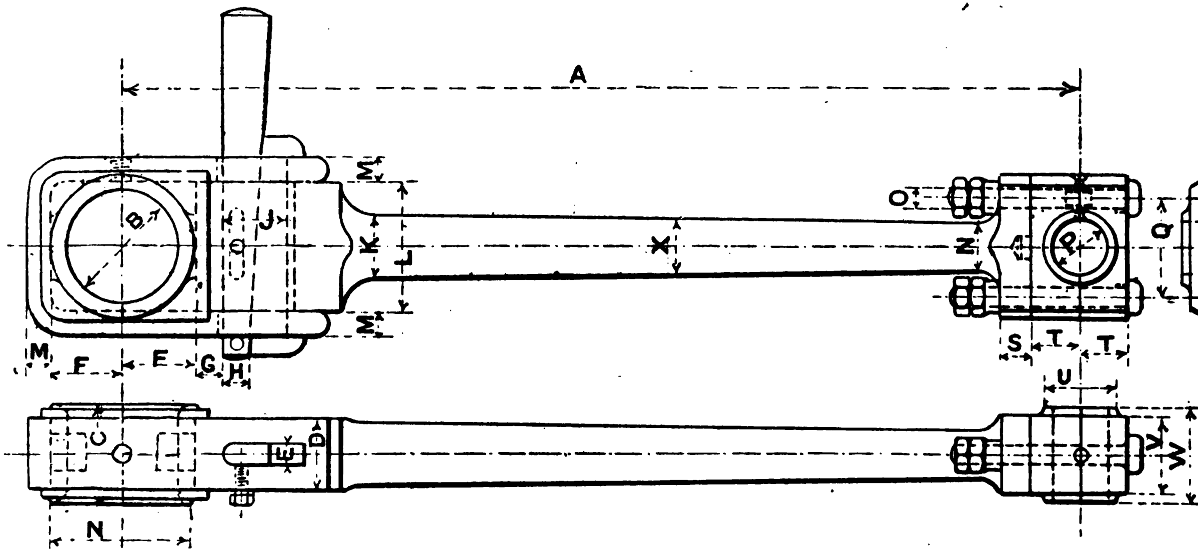
All Dimensions in Inches

Max. E.H.P.	Cylinder Diam.	Cylinder Stroke	A	B	C	D	E	F	G	H	J	K	L	M
* 6	7	10	$27\frac{5}{8}$	3	—	$2\frac{5}{8}$	$1\frac{1}{4}$	$2\frac{5}{8}$	2	4	—	$1\frac{1}{4}$	$\frac{5}{8}$	$1\frac{5}{8}$
13	$8\frac{1}{2}$	18	48	4	$5\frac{1}{8}$	$3\frac{1}{8}$	$\frac{7}{16}$	$3\frac{1}{8}$	$2\frac{3}{4}$	$4\frac{7}{8}$	$2\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$2\frac{1}{4}$
16	$9\frac{1}{2}$	18	49	$4\frac{1}{4}$	$5\frac{5}{8}$	$3\frac{1}{4}$	$\frac{3}{4}$	$3\frac{1}{2}$	$2\frac{7}{8}$	$5\frac{1}{2}$	$2\frac{1}{2}$	1	$\frac{3}{4}$	$2\frac{1}{2}$

Max. E.H.P.	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	*a*
* 6	4	$2\frac{3}{4}$	—	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{3}{4}$	$4\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	$2\frac{1}{8}$	—
13	5	$3\frac{1}{4}$	$6\frac{3}{4}$	2	2	—	—	—	$\frac{3}{4}$	—	$2\frac{11}{16}$	3	$2\frac{3}{4}$	4
16	$5\frac{5}{8}$	$3\frac{1}{4}$	$7\frac{1}{8}$	$1\frac{7}{8}$	2	$3\frac{3}{16}$	$5\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$1\frac{1}{2}$	$2\frac{5}{8}$	3	$2\frac{3}{4}$	—

* Vertical engine

FIG. 83.—CONNECTING RODS



All Dimensions in Inches

Max. E.H.P.	Cylinder Diam.	Cylinder Stroke	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
$3\frac{3}{4}$	6	9	$22\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{5}{8}$	$\frac{1}{2}$	$1\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{5}{8}$	3	$\frac{5}{8}$	$1\frac{3}{8}$	$\frac{1}{2}$	$1\frac{3}{8}$	$2\frac{3}{4}$	$3\frac{7}{8}$	$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{7}{8}$	$2\frac{1}{8}$	—
9	8	12	30	$3\frac{1}{2}$	$3\frac{1}{4}$	$2\frac{3}{8}$	$\frac{5}{8}$	$2\frac{1}{4}$	$\frac{7}{8}$	$\frac{11}{16}$	2	2	$4\frac{1}{8}$	$\frac{3}{4}$	$1\frac{1}{2}$	$\frac{5}{8}$	$1\frac{3}{4}$	$3\frac{1}{8}$	$4\frac{1}{2}$	1	$1\frac{1}{2}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	—
35	13	21	63	$5\frac{3}{4}$	$5\frac{3}{4}$	$3\frac{1}{2}$	$\frac{7}{8}$	$3\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{1}{4}$	$6\frac{5}{8}$	$1\frac{1}{4}$	$2\frac{1}{4}$	1	$3\frac{1}{2}$	$5\frac{1}{4}$	$7\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{3}{4}$	$4\frac{1}{2}$	$3\frac{1}{4}$	$4\frac{3}{4}$	$3\frac{1}{4}$

FIG. 84.—CONNECTING RODS

half part of a brass bush, and machined so that the other part of the brass fits in such a manner that it forms in itself a cap containing the lubricator. Two bolts, which (as the thrust is taken up by the rod) may be of small diameter, hold this cap in position. The small end is fitted with a split bush, the adjustment being made by a geared screw on its extreme end, with the spindle of the pinion carried through to the front so that a box spanner may be used. The other form of small end cannot be commended, as it is impossible to tighten the brasses without disconnecting the rod.

The type of connecting rod shown in fig. 84 is used only by Robey & Co. Since the force of the explosion is delivered to the crank on the outward stroke only, the rod may be taken as one piece; and as little or no stress is taken up by the outer brass, little strength is required in the strap, gib, and cotter. The cotter having a taper of 1 in 16, the very finest adjustments may be made. The small end is of the marine pattern, and easily tightened from the front.

Lubricator for Large End of Connecting Rod

The lubricator shown at fig. 84A is the pattern used on the large end of the above connecting rod, and the author, whilst

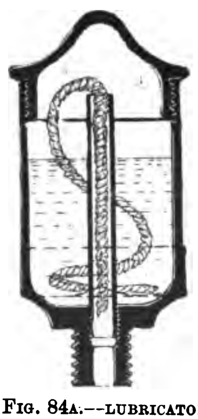


FIG. 84A.—LUBRICATOR

making some experiments, tested one of this form upon a crank pin 2·5 inches × 3 inches running 260 revolutions per minute.

The pin was kept cool throughout a continuous run of eleven hours, during which time only 1 cubic inch of oil was used, and the results showed that the general features, including the regulation of the supply, made this one of the very best forms for the purpose.

CHAPTER IX

GOVERNORS

GOVERNORS used on gas engines are mechanical combinations in which the centrifugal force developed is balanced and opposed

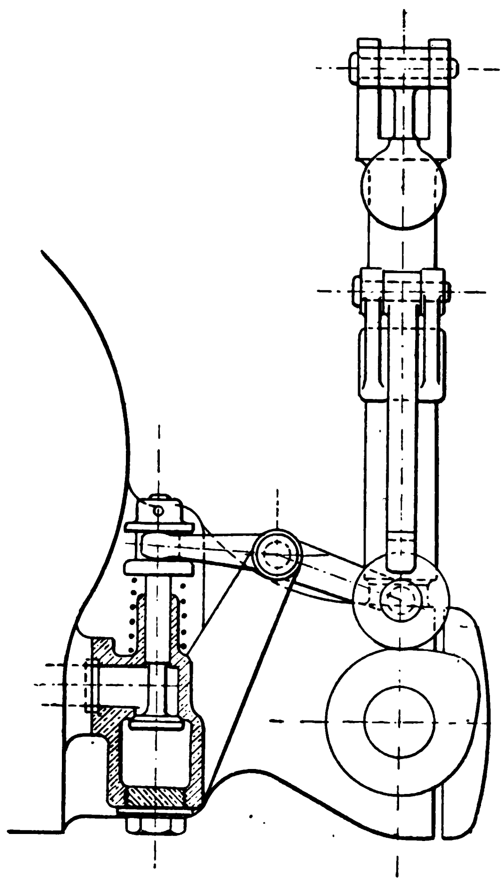


FIG. 85.—RICHARDSON GOVERNOR (ROBEY & CO.)

by dead-weights, springs, or other resistance, and are mostly arranged to run at an average speed, determined by the conditions under which the engine is employed, with a margin of variation usually allowed in the design, generally ranging from 2 per cent. for engines where great steadiness is a desideratum

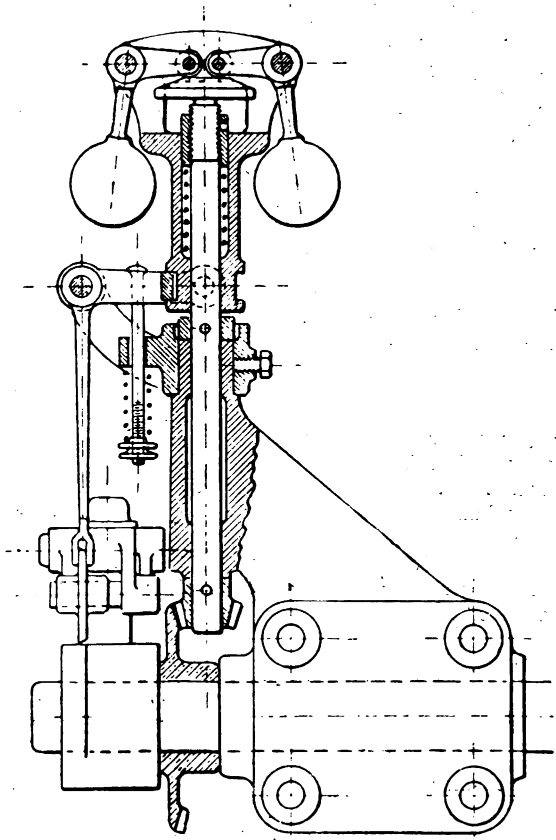


FIG. 86.—RICHARDSON GOVERNOR (ROBEY & CO.)

to 5 per cent. for ordinary purposes. Governors may be classified as follows :

1. The centrifugal form with (A) spring and (B) dead-weight resistance.

2. The inertia governor in its various forms.

The best known of the spring form of governor is that used by Messrs. Robey & Co., of the 'Richardson' type, which consists of a spring and revolving weights having great lifting and thrusting power, the sleeve being raised from the lowest to the highest position with a slight variation of speed.

Figs. 85 and 86 are sectional end and transverse elevations of a governor suitable for a 24 B.H.P. engine, and clearly show its construction and action. The following formulæ were used in its design, and as it would involve too much calculation to obtain strict accuracy, a margin of $\frac{1}{4}$ per cent. is close enough for all practical purposes.

It was assumed in making the following calculations that the governor arm was hanging vertically, and the short arm resting upon the pad, formed a right angle with it.

In a well-designed governor disturbing action may be neglected, since its object should be to signal to a separate part of the engine to perform the work, such performance being carried out without interfering with the governing proper.

Weight of governor head, two arms, balls, spring, and two pins	= 7·25 lbs.
Weight of two balls and arms	= 3·25 lbs.
Spring at rest	= $2\frac{1}{2}$ ins. long
„ internal diameter	= $\frac{7}{8}$ inch
„ external „	= $1\frac{1}{8}$ inch

Number of coils, 10. B. W. G., 12.

Proportion of arm leverage = 5 to 3. Revolutions of driving shaft = 90.

Gear 48 to 13

$$\begin{array}{r} 90 \\ \hline 13)4320 \\ 39 \\ \hline 42 \\ 39 \\ \hline \cdot 30 \end{array} \quad \left\{ \begin{array}{llll} 295 & \text{revolutions per minute,} & & \text{bottom position} \\ 332 & \text{„} & \text{„} & \text{mean position} \\ 369 & \text{„} & \text{„} & \text{top position} \end{array} \right\}$$

Weight of one 2-inch ball = 1·1 lb.

Position	Radii	Revolutions
a	·1666′ = ($\frac{1}{6}$′)	295
b	·1875′ = ($\frac{3}{16}$′)	332
c	·20833′ = ($\frac{5}{24}$′)	369

Centrifugal force formula. ·00034 × weight × radii in ft. × revolutions.^{2}

Centrifugal force :—

a $\cdot 00034 \times 2\cdot 2 \times \frac{1}{6} \times 292^2 = 10\cdot 849$

b $\cdot 00034 \times 2\cdot 2 \times \frac{3}{16} \times 332^2 = 15\cdot 458$

c $\cdot 00034 \times 2\cdot 2 \times \frac{5}{24} \times 369^2 = 21\cdot 218$

Force acting on pad due to centrifugal force of balls =

Position	Radii		lbs.
a	$\frac{5 \times 10{\cdot}849}{3}$	=	18·0817
b	$\frac{5 \times 15{\cdot}458}{3}$	=	25·763
c	$\frac{5 \times 21{\cdot}218}{3}$	=	35·363

Force acting on pad due to centrifugal force on pad − weight of governor head, balls, arms, springs, pins, &c. = required spring resistance.

a $18{\cdot}0817 - 7{\cdot}25 = 10{\cdot}8317$ lbs.
b $25{\cdot}763 - 7{\cdot}25 = 18{\cdot}513$ „
c $35{\cdot}363 - 7{\cdot}25 = 28{\cdot}113$ „

The Robey Governing Gear

In governing a large engine the conditions are somewhat different from those which obtain in small engines; for though

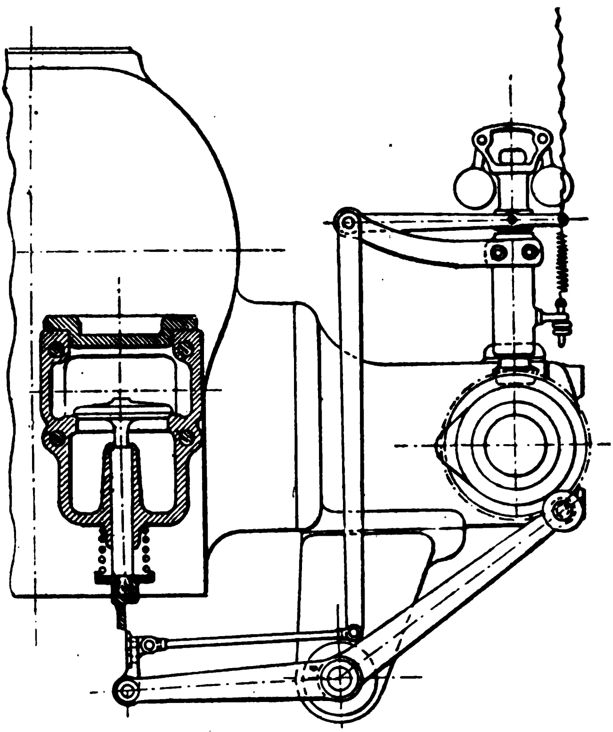


FIG. 87.—ROBEY GOVERNING GEAR

the ordinary gas roller works well on small and medium sizes—even when arranged for 'close' governing—when applied to large ones it is a source of trouble, owing to the small amount of surface contact under heavy lifting pressure. In fig. 87, which is the governing arrangement used on a large-size Robey engine, it will be seen that so long as the governor is in its mid-position, the gas valve is lifted by the lever A, the connecting levers from the governor being so designed that no disturbing action takes place; but immediately the load is released, the striking pecker is pulled out of action and a cut-out effected. Graduated notches are, however, arranged on the end of the gas valve spindle when the engine is used for electric lighting. The lifting pecker, as well as the end of the gas valve spindle, is made of tool steel, case-hardened, and has very broad striking edges.

If, through any cause, the normal speed of the engine be considerably increased, so that the governor assumes a position midway between its normal and the highest, the pecker is moved out of action to such a point that it acts as a strut, and holds the governor in that position until the engine stops. This feature enables a communication to be made by a wire with any part of the building or offices, so that in case of accident the engine may be readily brought to a standstill.

Crossley's Centrifugal Governor

Messrs. Crossley's dead-weight governor (as shown at fig. 88) was introduced by them in the early days of gas engines, and has retained its form to this day. The sleeve is not in contact with the counterpoise until the engine has attained a certain speed, it is until that time an unloaded governor; but for all practical purposes may be treated as a loaded one, and by varying the weight of the poise the speed of the engine may be altered.

Crossley's Inertia Governor (Patented in 1881)

Fig. 89 is an elevation and fig. 90 a plan of an inertia governor arranged on a vertical engine.

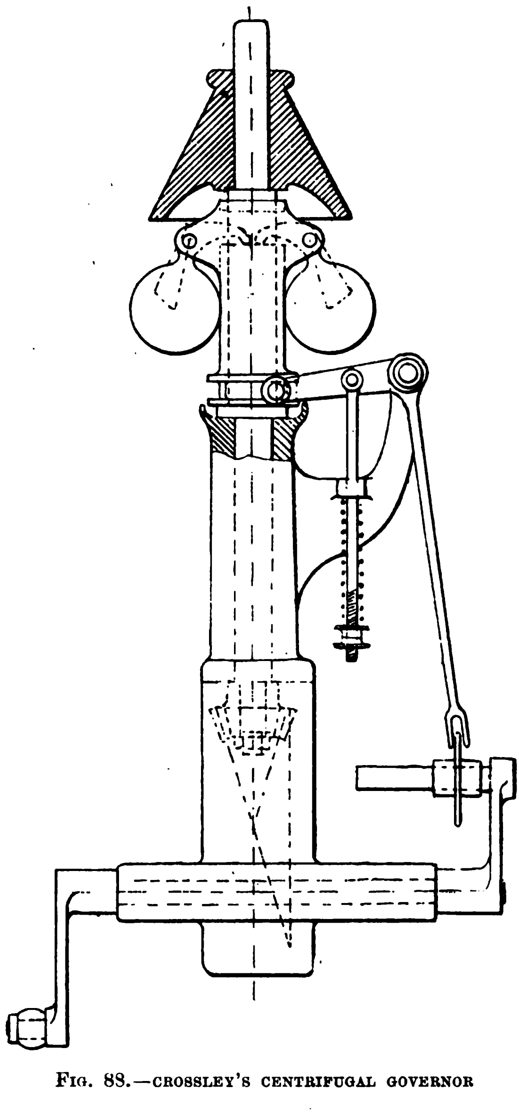


FIG. 88.—CROSSLEY'S CENTRIFUGAL GOVERNOR

A is the vertical second motion shaft, and B the cam which operates the lever, which in this case is used for operating the gas and air valves, the air valve being worked by the pro-

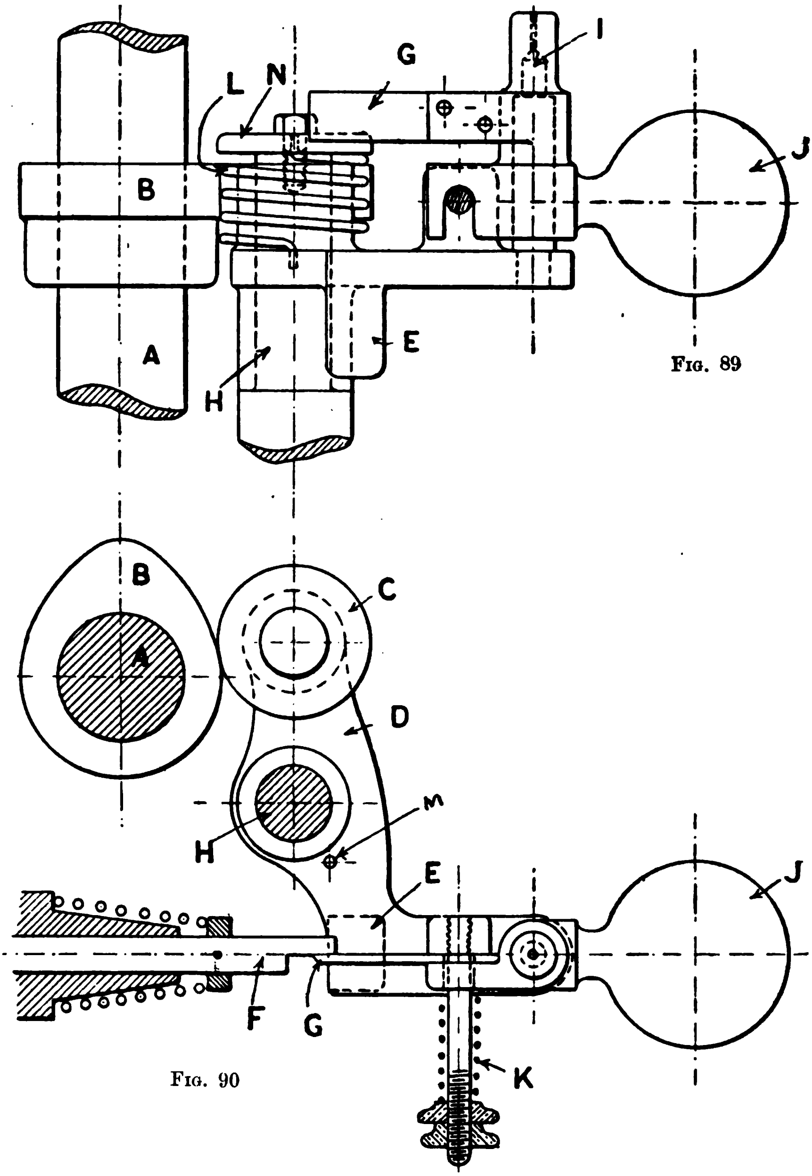


FIG. 89

FIG. 90

FIGS. 89, 90.—CROSSLEY'S INERTIA GOVERNOR

longation E; F is the gas valve spindle and G the striker, H is the fulcrum, I the pivoted centre on which the governor weight J vibrates, and K the regulating spring. The roller C is held hard against the cam B by means of the spring L, which is attached to the lever D at M, and the pin H by means of a washer N, which is held in position by a set screw. The lever D has under all conditions a constant travel; therefore there is no variation in the lift of the air valve. Fig. 90 shows the striker in position for taking in a full charge of gas, and if the spring K is fully compressed the gas valve would then also be opened at every charging stroke; but since the spring K is not fully compressed, and, when the engine is running above its normal speed, the ball J is left behind, the striker assumes such a position that it misses the gas valve F until the normal speed has been regained.

As this governor works exceedingly well, it is difficult, considering its simplicity, to see how it can be improved upon.

Tangyes' Incline Governor (*Patented in* 1885)

This is another form of inertia governor, and is shown as arranged for horizontal engines in elevation fig. 91 and end view fig. 92, the characteristic feature being that it can be worked in almost any position.

The second motion shaft A is provided with a cam B to actuate the lever C, having an incline attached carried by a swinging arm D, centred on a pin E fixed to any suitable part of the engine. This swinging arm has projections F and G, to which are attached the springs H J, the spring H serving to keep the roller K against the cam B, whilst the spring J is used for regulating the speed of the engine.

When the engine is working at its normal speed—i.e. the speed decided upon by the amount of tension put on the spring J—the incline lever C rides up the roller S until the pecker L strikes the lever M, and opens the gas valve O; but if the speed of the engine increases beyond its proper rate, the lever will ride up the roller at a greater velocity, and its inertia carries the pecker over the top of the lever M and effects a cut-out.

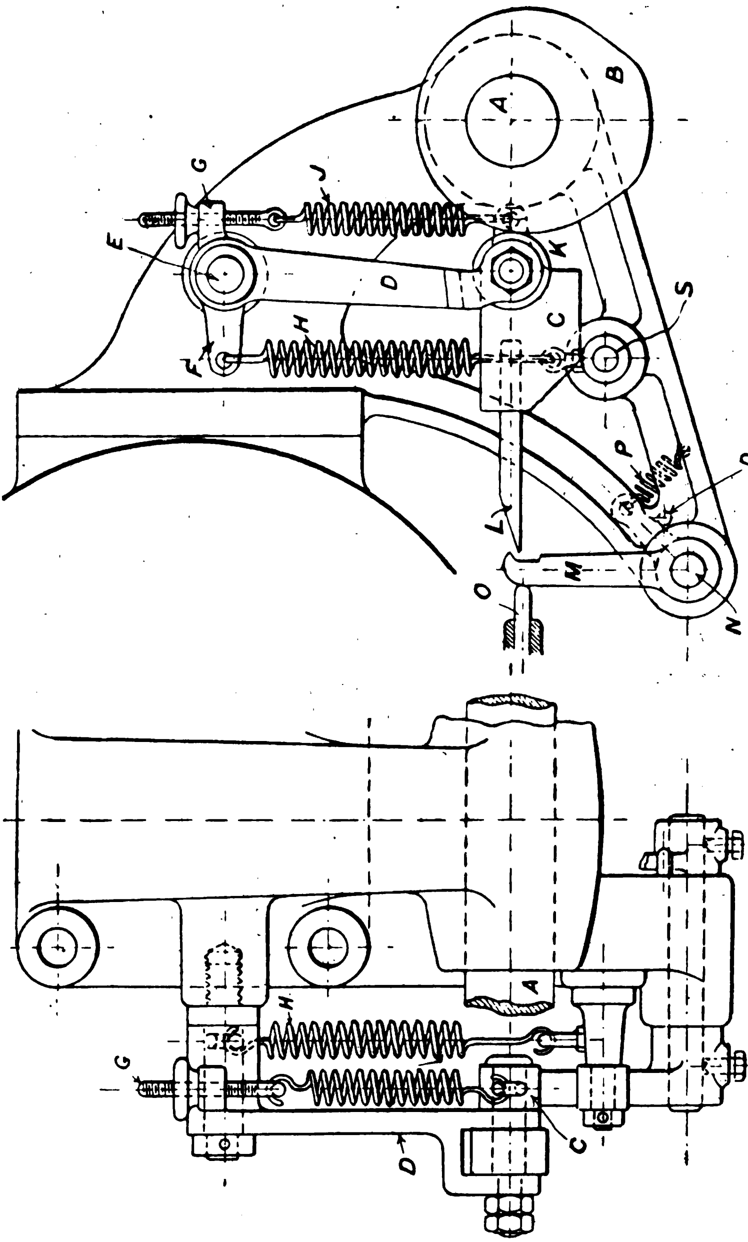


FIG. 91

FIG. 92

FIGS. 91, 92.—TANGYES' INCLINE GOVERNOR

The lever M is brought back to its normal position by the spring P, and as the gas lever is fitted with its own recoiling spring, they always follow the return of the striking lever.

To ensure this governor working satisfactorily it is absolutely necessary that the worm wheels driving the side shaft shall be machine-cut, with practically no ' back lash.'

' Stockport' Vibrating Governor

A very neat form of vibrating governor is made by Messrs. Andrew & Co. Fig. 93 is an external end elevation partly in section, fig. 94 a plan, and fig. 95 a view showing the weight and connection to the lever.

The action is as follows :—A weight A, riding on a spring C, is moved by a vibrating lever B, and so long as the engine runs at a certain speed the weight keeps in position a small pecker G, and the gas enters the combustion chamber; but on the work being thrown off, or a variation of speed taking place above the normal, the weight immediately takes up a different position, moving with it the pecker, and the gas is cut off. The speed of the engine can be readily adjusted by the nuts E E′. A simple method of taking up the wear of the pecker is by the set screw D, the pecker being raised in the slot on the lever B.

The action of this governor does not necessarily depend on inertia. The weight takes up a different position on the speed increasing because the spring has more work to do—that is to say, it has to lift the weight in a shorter space of time. This it fails to do, and therefore the weight compresses the spring, and in doing so operates on the bell crank lever, and the cut-out takes place.

Another form of governor made by this firm is of the centrifugal type, worked by spur gearing off the cross shaft, and through a lever made to act on a bell crank in communication with the gas valve.

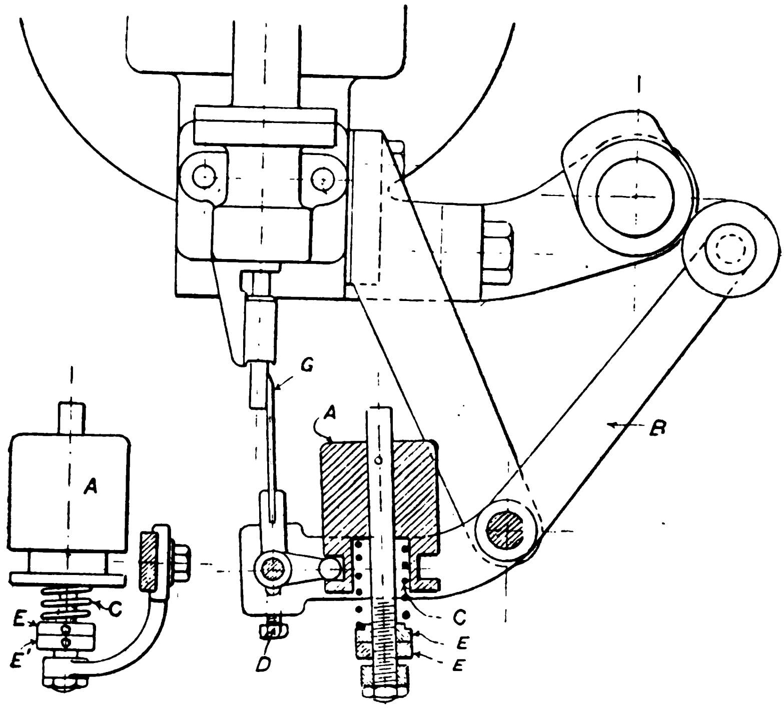


FIG. 95 FIG. 93

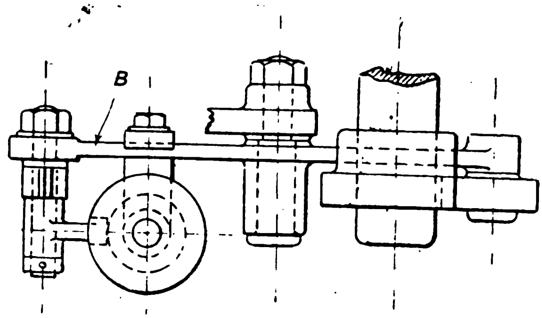


FIG. 94

FIGS. 93, 94, 95.—STOCKPORT VIBRATING GOVERNOR

Electric Governor

In 1883 Professor Thompson made a series of tests with a governor designed by Mr. John Richardson, M.I.C.E., of the firm of Robey & Co., and used on steam engines for electric lighting,

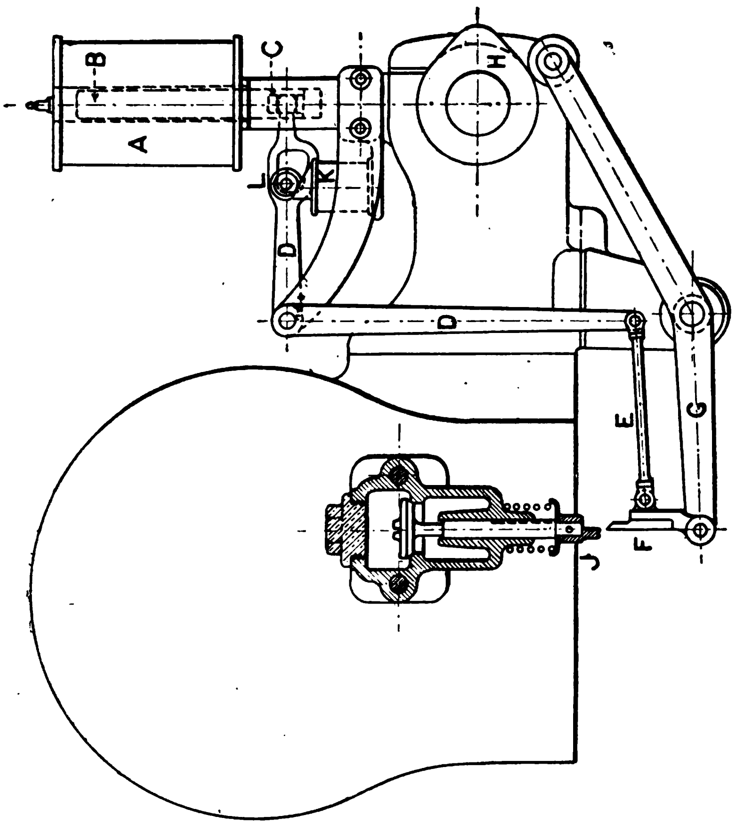


Fig. 97

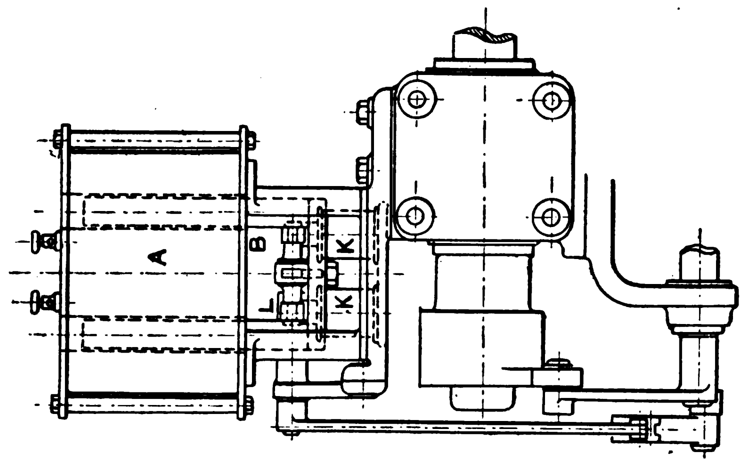


Fig. 96

Figs. 96, 97.—Robey Electric Governor

wherein the regulating power was obtained from the electric current itself.

An application of this principle to a gas engine is shown at figs. 96 and 97, which consists of a pair of solenoids A, with laminated iron cores B, having a connecting stud C, crank lever D and rod E, directly attached to the pecker F, which is actuated by a cam G and lever H. The solenoids being wound to regulate a current of varying quantity are connected as a shunt from the main current, the power required being about 120 watts.

The engine is started in the usual way, the speed and current increasing until the solenoids are converted into a powerful electro-magnet, the iron cores being magnetically drawn or sucked within the coils, and there held in suspension. Should the normal voltage be exceeded, the cores rise slightly and draw the pecker away from the gas valve J, and the engine receiving no impulse, and decreasing in speed, the cores fall until the pecker is brought into action again. Should the driving belt break or fly off the pulley, or the main circuit be broken, the safety electro-magnet K releases the roller L, and the cores drop to their lowest point, and, bringing the pecker out of action, the engine is brought to a standstill.

This is a very delicate form of governor, as the slightest change in current causes an instantaneous adjustment of the gas inlet.

It is not an unusual practice even now to find gas engines which are used for driving dynamos with the governor out of action, and the gas cock regulated to suit the load. This has been rightly described as a 'one-man automatic regulator—i.e. a man sitting with his hand on the gas cock handle and his eye on the voltmeter.'

CHAPTER X

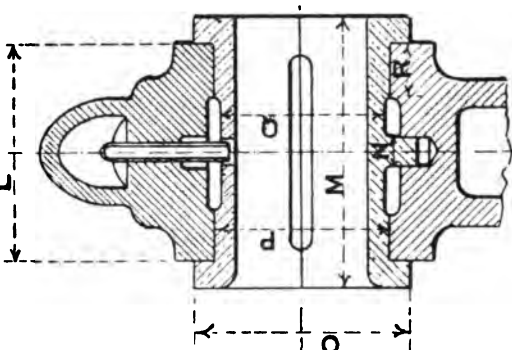
CRANK SHAFT BEARINGS

THE crank shaft bearings form such an important part of an engine that they require special care both in design and construction.

The general practice is to use the simple form having a two-part brass, adjusted by a cap and bolts; the division line of brass in this type is usually at an angle of 45° to the centre line in horizontal engines. The practice of manufacturers differs as to the position of the cap to resist the explosion; in some cases it is thrown upon the cap and bolts as in fig. 11, where the cylinder is placed to the right hand of the bearing. The method generally followed, however, is to place the cylinder to the left hand, as in fig. 5, this being the preferable position, comparatively little strain being thrown on the cap, as the force of explosion is taken directly by the main bed casting. The bottom brass has a toggle N, fitted in a recess of the main casting, to prevent the brasses revolving with the shaft. In this form of bearing the brasses should be bored 0·05 per cent. larger than the diameter of the shaft, to prevent them closing in and pinching the shaft should they become warm.

The table of sizes in figs. 98 and 99 are from actual practice, and may be taken as typical sizes used by leading makers in this form of brasses. In vertical engines the division line is usually placed horizontally, the strain of the explosion being taken up by the cap if the cylinder is below the crank shaft, and by the bed if the cylinder is above. This makes a very efficient bearing and gives uninterrupted bearing surface. In some designs of beds, especially for the larger size of horizontal engines, the bearing shown in fig. 98 is unsuitable, and as it is not permissible for the division line of brasses to be on the horizontal centre line of the engine, it becomes necessary to use brasses in four parts, as shown in figs. 100 and 101, which are taken from a large size Robey engine, as they are adjustable both vertically and horizontally; the vertical adjustment being effected by the cap and bolts, and the horizontal adjustment by means of wedges drawn up by nuts coming through the cap. These wedges are only placed on the side nearest the cylinder, so that there is no strain on them from the force of the explosion. In this type of bearing the steps are of cast iron lined with Babbitt metal, which gives excellent results. The flanges of the two side steps are made with projecting lips to butt against the flanges of the top and bottom steps, by which means

they form one rigid bearing, and prevent adjustment until they have been eased the required amount, making it impossible to



Section through X. Y.
FIG. 99

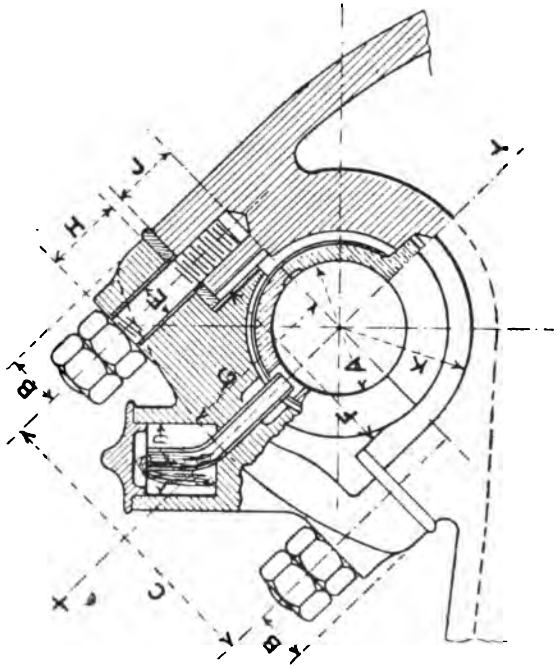


FIG. 98

All Dimensions in Inches

Max. E.H.P.	Cylinder Diam.	Cylinder Stroke	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	Q	R
7	7½	11	2¾	1⅛	6¼	1½	¾	4⅜	3½	1⅝	1⅜	2¾	4⅜	5½	⅝	4½	3⅝	3⅛	1⅛
24	11	18	4	1½	8¾	2	1⅛	6½	5	2½	2	4	6½	8	¾	7	5½	5¼	1½
43	14	21	5½	2	11	2¼	1½	8⅛	6½	2⅞	2¾	5⅛	9¼	11	1¼	9	7¼	6⅞	2

FIGS. 98, 99—CRANK SHAFT BEARINGS.

throw the bearing out of line. The gap for the bearing is bridged by a massive cap provided with lugs at each end, fitting tightly

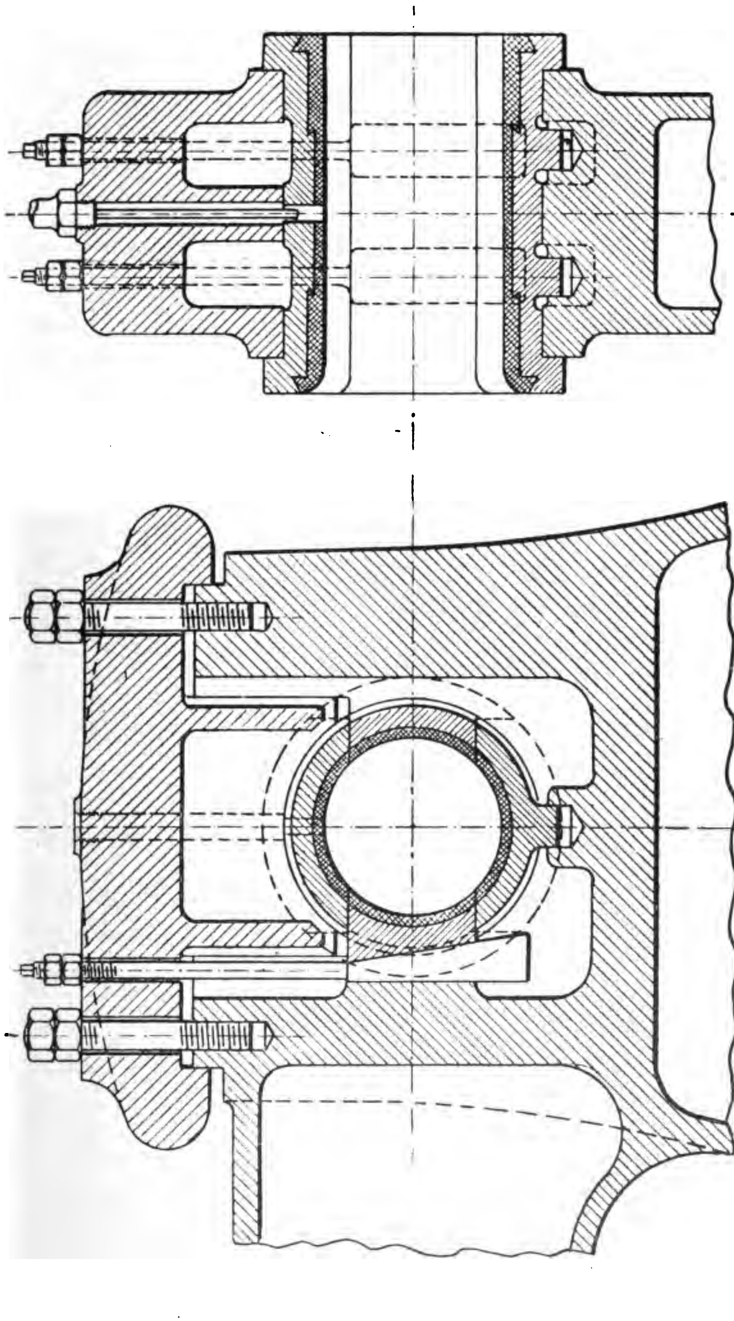


Fig 100

Fig. 101

Figs. 100, 101.—Robey Crank Shaft Bearing

on the bed casting, and effectually tying the bed together at this point. In bearings having four-part brasses, 0·08 per cent. larger than the shaft is necessary.

A good practice in determining the size of crank shaft bearings is to allow a maximum pressure of 400 lbs. per square inch of rubbing surface. Assuming that the maximum pressure of the explosion is transmitted direct to the crank pin.

$$\therefore \frac{P \times A}{D \times L} = \text{Pressure per square inch of rubbing surface.}$$

Where D = diameter of shaft in inches; L = length of bearing in inches; P = maximum pressure of explosion; A area of cylinder; the rubbing surface being taken as approximately one-third of the circumference—i.e. diameter × length.

Owing to the effect of the inertia of moving parts (as shown in fig. 61), the maximum pressure per square inch on piston does not reach the main bearings. Then the above formulæ may be used, and the allowable maximum pressure will be 180 lbs. per square inch of rubbing surface.

Some makers prefer to speak of the pressure on bearings based on the average pressure per square inch on piston, but as already explained this is not to be commended.

The Lubrication of Bearings

The lubrication of main bearings is of great importance, and efficient means should always be provided for the distribution of the oil, or solid lubricant if such is used instead of oil.

A very common method is shown at fig. 98, a piece of wick being the means, by capillary attraction, of feeding the oil; although this is somewhat wasteful, practice has proved it to be very reliable. There are many compounds of greases, sold in a semi-liquid and solid form, suitable for main bearings; but these have to be used with great care, as the extra width of oil grooves necessary for their use reduces the bearing surface of the brasses, and in addition to which, the varying temperatures of the engine-room and the susceptibility of the greases to liquefy by heat and run through, cause many heated bearings.

These solid lubricants should never be used for crank necks or moving parts.

CHAPTER XI

WORM GEARING FOR SIDE SHAFT

THE type of gearing used by all the gas engine makers to transmit the power at right angles to the side shaft is a form of worm and worm wheel, geared as 2 is to 1, the friction of which must of necessity be more than that of bevel or spur gearing, but can be reduced to a minimum by the use of well-lubricated machine-cut gear.

Both the driving and driven wheels are part of multi-threaded screws, the cross section of the teeth being the same,

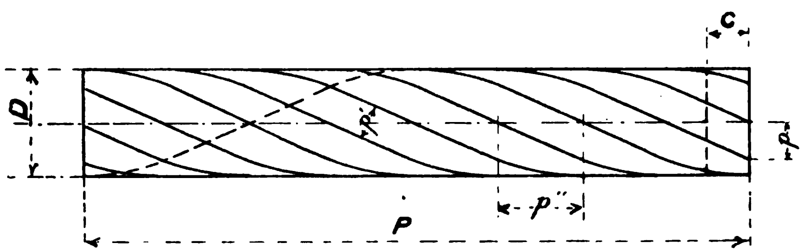


FIG. 102

but the angle of the threads on the driver being twice that of those on the driven wheel, and double the number of teeth or sections of thread on the same size of wheel. If fig. 102 be taken as an eight-threaded screw, with P as the pitch and D as the diameter, the section C would form a worm wheel of eight teeth. In each wheel there are four distinct pitches:

P = the pitch of the helix;

p = the circumferential pitch, measured from centre to centre of threads around the circumference;

p^1 = the normal pitch, measured at right angles with the direction of the threads;

p^2 = the axial pitch.

In all worm and worm wheels the normal pitch (p^1) must be the same in both wheels, and it is upon this pitch that the

wheel teeth are designed, and to which templates should be made for working, the other pitches varying in the two wheels.

The worm and worm wheels shown in figs. 103 and 104 were designed for a 13-inch × 21-inch engine, the diameter of both wheels at the pitch circle being 9 inches—i.e. the centres of the crank shaft and side shaft were 9 inches apart. There are

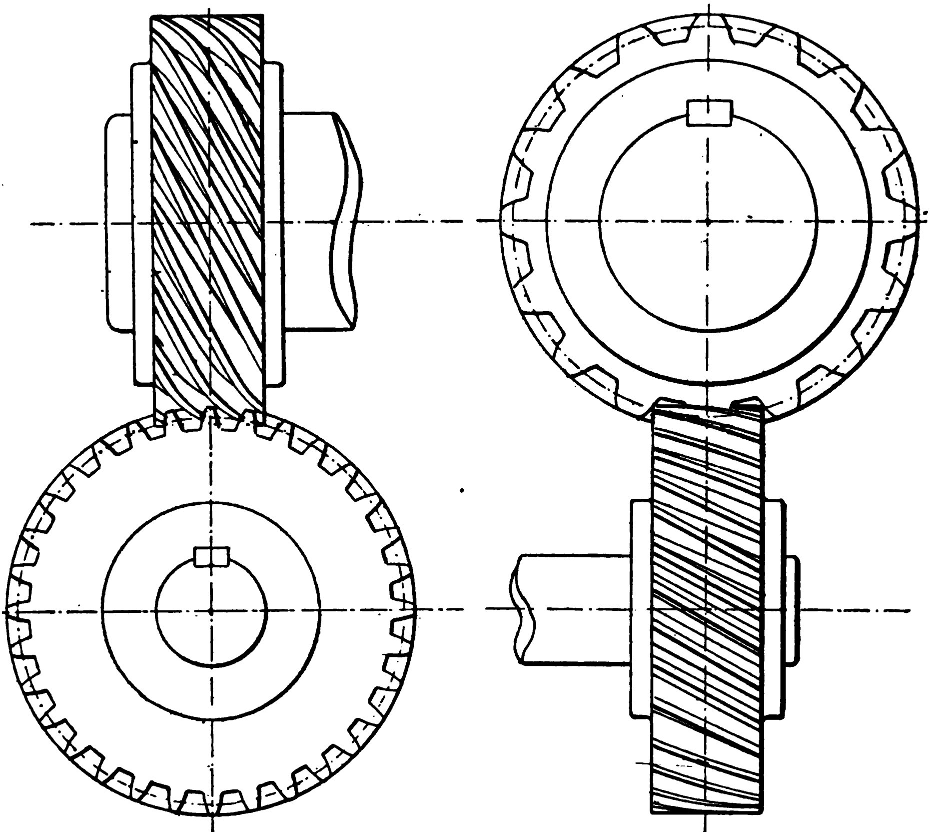


FIG. 103

FIGS. 103, 104

sixteen teeth in the worm and double that number (thirty-two) in the worm wheel. The pitch of the screw thread in the worm equals half the circumference of the pitch circle = 9 inches diameter $\times 3{\cdot}1416 = \frac{28{\cdot}27}{2} = 14{\cdot}13$ pitch of screw thread. If

we mark off the pitch of the thread on a horizontal line A B (fig. 105), and on a line perpendicular to A B mark off A C equal to the circumference of pitch circle, and join B C, the angle this line makes with A B gives the angle of thread, which is approximately 63°.

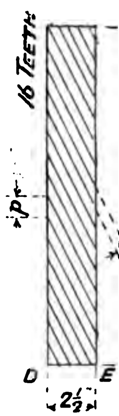


FIG. 106

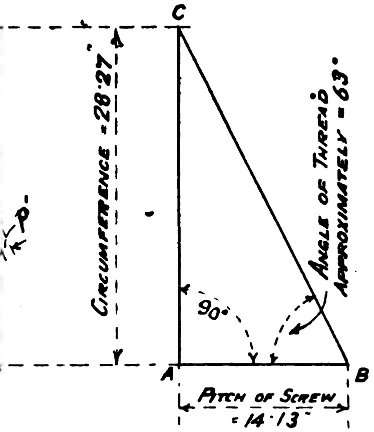


FIG. 105

In the case of the worm wheel the pitch of the screw thread equals double the circumference of the pitch circle = 9 inches diameter × 3·1416 = 28·27 × 2 = 56·54 inches pitch of screw

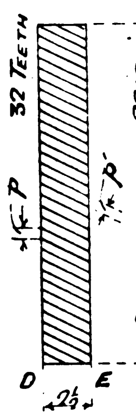


FIG. 108

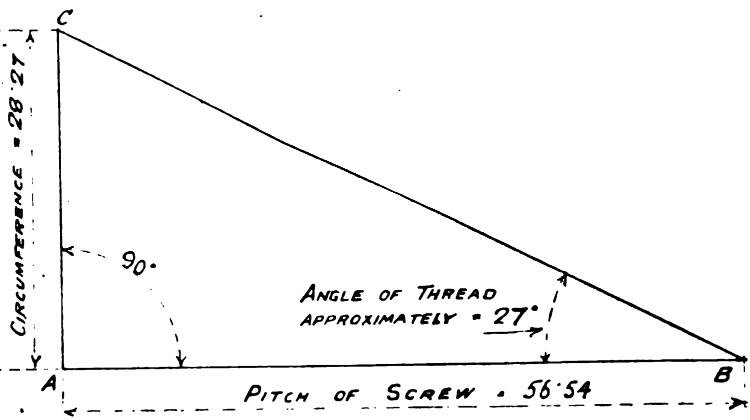


FIG. 107

thread, and drawing this out as in fig. 107, and the angle the line

B C makes with A B gives the angle of thread, which is approximately 27°, the angle of thread in the worm plus the angle of thread in wheel equal a right angle.

This rule for finding the angle of thread is applicable to any pair of worm and wheel of equal diameter, and geared 2 to 1.

Dividing the circumferences into their respective numbers of teeth, as in figs. 106 and 108, making D E equal the width of wheels = $2\frac{1}{2}$ inches, and drawing the centre line of teeth parallel to their respective angles, the normal pitch p'—in this case $\frac{28}{32}$ inches, can be measured off, and it will be found the same

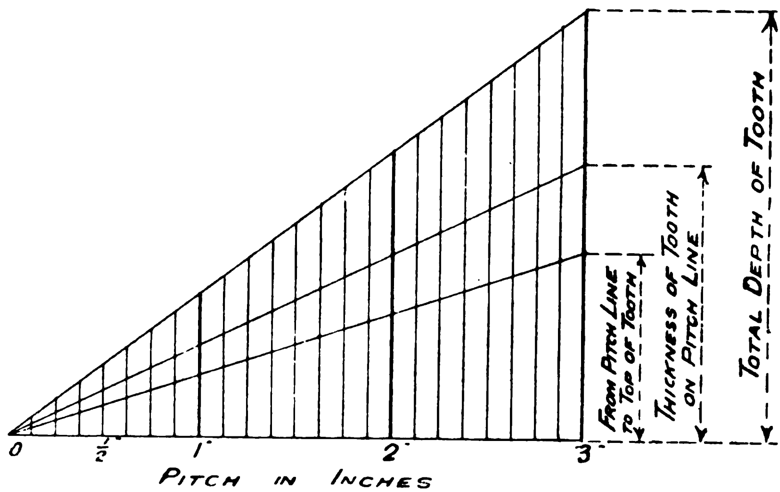


FIG. 109

in both wheels. From this normal pitch the height of tooth above pitch line (which gives the outside diameter of the wheels) and the depth of tooth below the pitch line and the width of tooth at the pitch line are obtained from fig. 109. As in the case of ordinary spur gears, the contour of the tooth can be struck out either cycloidal or involute, the latter being preferable, as it is not only an easier curve to construct, but works well in practice.

Fig. 110 shows the construction of the involute curve.

Draw a line at 75° with the centre line of the wheels at the point of contact with the pitch circles, and a circle A B, drawn tangentially to this line will be the describing circle, upon which

set off the distances *a b*, *b c*, *c d*, *d e* from *a*, the edge of the tooth, and draw tangents to same; then set off the distance *b b'* equal to the arc *b a*, the distance *c c'* equal to the arc *c a*, the distance *d d'* equal to the arc *d a*, &c., and the curve drawn through these points will be the involute required. Having set off the pitch, height, depth, and width of teeth, as per figs. 109 and 110, and drawn the flanks by the involute obtained, the root from *f* to *g* may be a straight line parallel to the centre of the tooth, with a rounded corner.

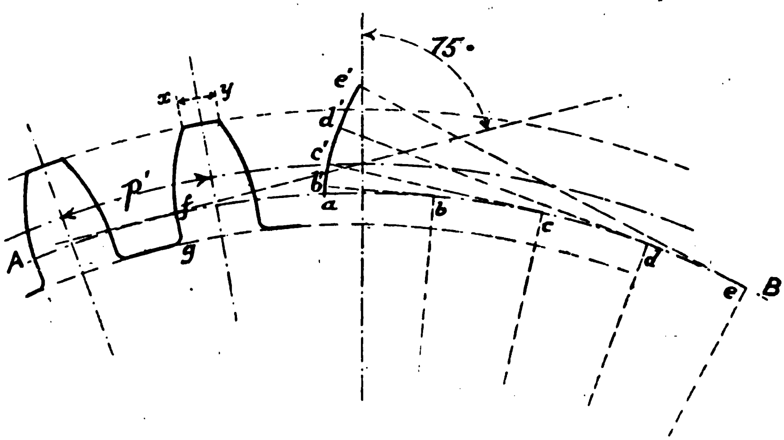


FIG. 110

The angle of a screw varies according to the distance away from the centre or axis of screw, notwithstanding that the pitch of screw is constant. This will be seen from figs. 111 and 112, where the angle of thread is given at three distances from axis —viz. the diameter at root, the pitch circle, and the diameter at point of teeth.

The letters and numbers in figs. 111 and 112 correspond. A B being the axis of screw, P the pitch, D C the height of tooth above pitch line of wheels, and D E the depth of tooth below, divide the circumferences of the transverse section F, also the pitch of screw P, into the same number of equal parts—1, 2, 3, &c.—and draw lines through the points of intersection, as shown at 1', 2', 3' &c. This will give the twist of screw

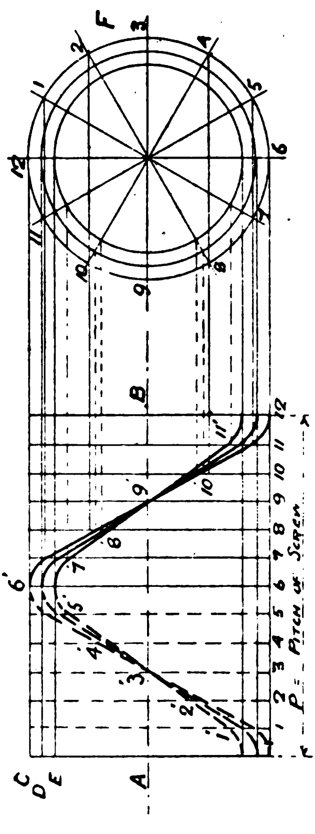


Fig. 111

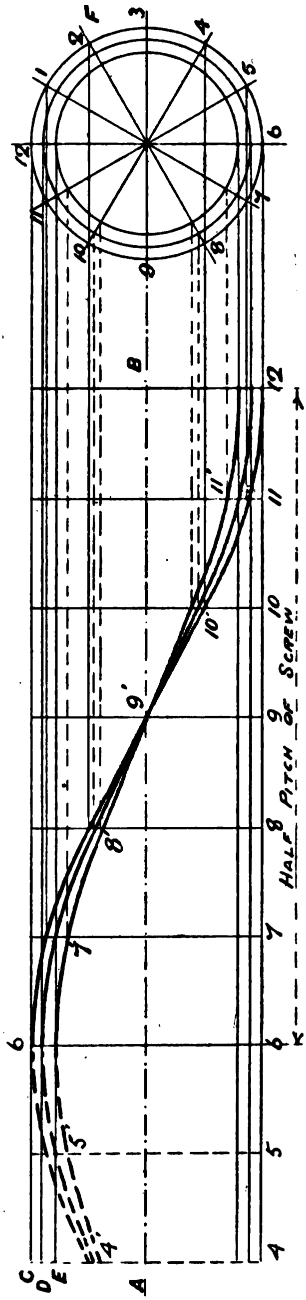


Fig. 112

thread C on the cylinder. The same construction is followed out for the twist of thread at pitch circle D and at root of teeth E.

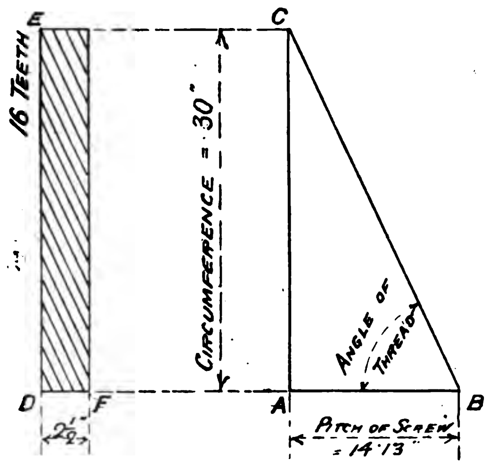


FIG. 113 FIG. 114

FIGS. 113, 114

Knowing the angle of the curve D, all that is now necessary is to find the angle of thread on outside diameter C. For the

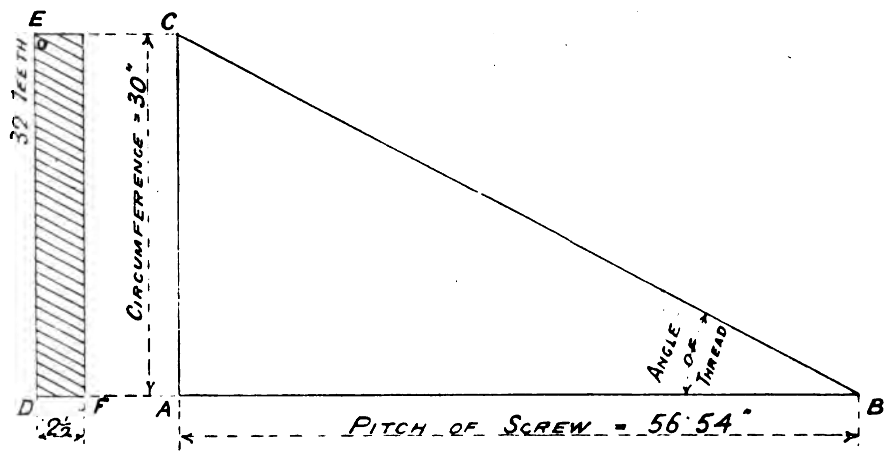


FIG. 115 FIG. 116

FIGS. 115, 116

worm set off the pitch of thread (14·13) on a horizontal line A B (fig. 113), and on a perpendicular to A B set off A C equal to the

circumference of the outside diameter of worm over the points of teeth or threads ; join B C, and the angle this line makes with A B equals the angle of thread in worm.

Fig. 116 shows the same construction applied to the wheel.

We now construct figs. 114 and 115, setting off D E equal to A C, and D F equal to width of worm and wheel (in this case $2\frac{1}{2}$ inches), and having divided D E into the number of teeth in worm and wheel respectively, draw the centre lines of teeth parallel to B C. If we mark off half the width of teeth at points $x\,y$ (fig. 110) on each side of these centre lines, and fasten these two

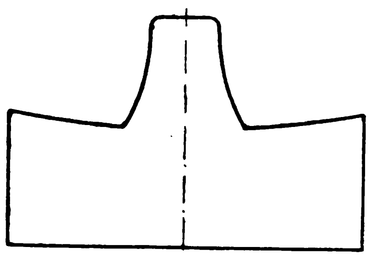


FIG. 117

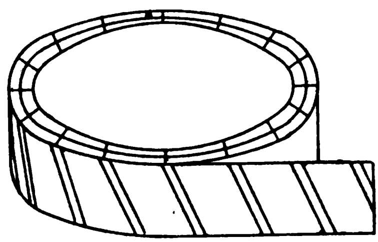


FIG. 118

strips on the outside of the wheel blocks (as in fig. 118), they will represent the true angles of the points of teeth for the worm and wheel. By making a template of the spaces between the wheel teeth (see fig. 117) we can by its aid cut out by hand the teeth spaces, holding the template in the position of normal pitch. After having worked two teeth to template, it is advisable to mark out the profile of teeth on the two faces of blocks, which must be taken from the actual teeth, as owing to the angle of teeth their profiles on faces of wheels are not symmetrical.

In machine-cut wheels it is only necessary to make the cutter to the shape of the tooth spaces (see fig. 117).

CHAPTER XII

VALVES

WITH very few exceptions, all the makers of gas engines adhere strictly to the mushroom type of valve, experience having proved that this form embodies the most advantages, as it works exceedingly well and admits of inexperienced men grinding them when necessary to their seats with an ordinary joiner's brace and flour of emery.

The author has known an engine in constant work in which the exhaust valve was not re-ground in until it had worked for sixteen months, and the air valve was not taken out within the first two years; this practice is not to be commended, but is only quoted to show how long an engine working free from dust will run without attention, so far as the valves are concerned.

The length of time to which an engine should be allowed to run before the air and exhaust valves are cleaned and ground in depends altogether on the quality of the gas and the oil used. Where both are good and the engine-room free from dust, the air valve should be taken out once in three months, and the exhaust valve once a month.

Fig. 119 is a type of exhaust valve very largely used.

The method of lifting the valve by means of a pivot does not permit the versed sine of the lifting lever being taken up without throwing some strain on the valve spindle; and as the arrangement prevents the valve from turning on its seat, making it difficult to keep it tight, this principle should be either well designed or not used.

Fig. 120 is another type of valve and lifting arrangement both for air and exhaust valves. When used as an exhaust valve great difficulty is experienced from the spring becoming heated and losing its elasticity, although the valve is permitted to turn on its seat. The position for lifting when the valve is under the greatest pressure tends to strain the valve spindle. The method of adjustment in case of wear is very simple.

Fig. 121 shows a method of lifting the valve by means of a

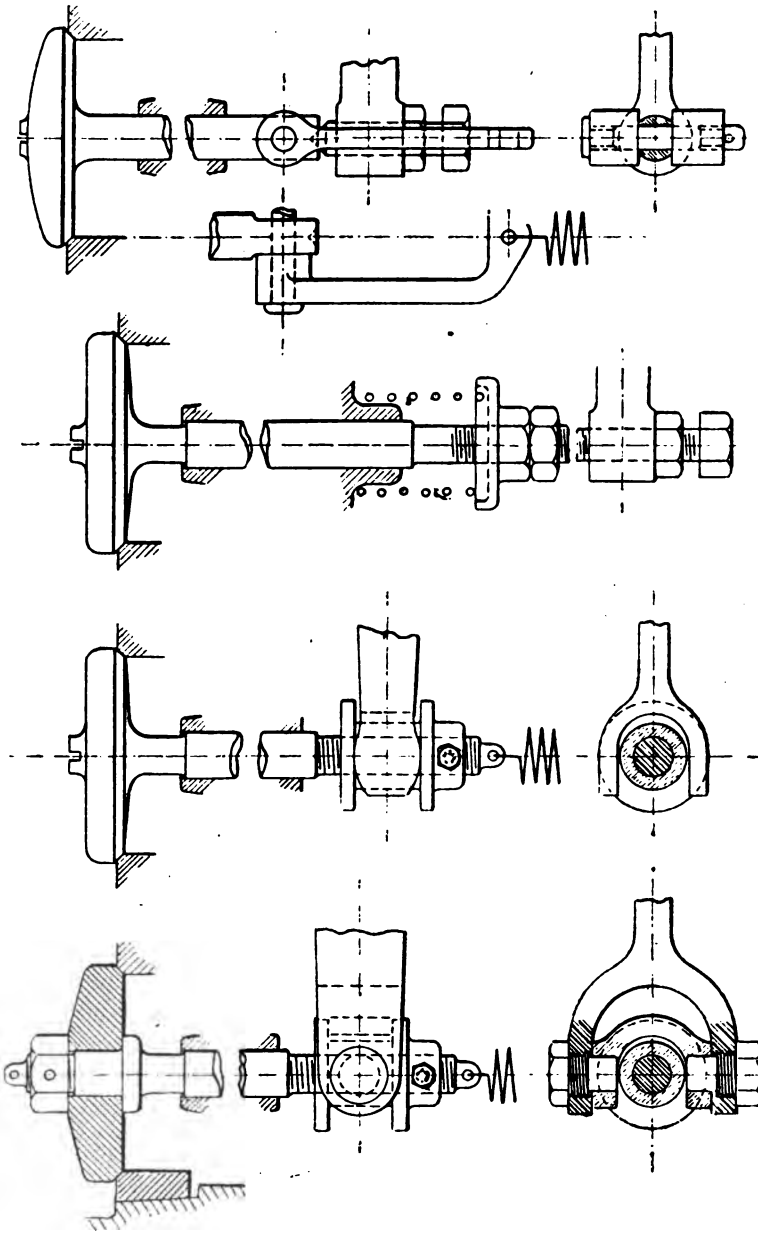


FIG. 119 FIG. 120 FIG. 121 FIG. 122

FIGS. 119, 120, 121, 122.—VALVES

spool and central spring attachment. Owing to the small amount of lifting lever surface contact, very little strain is thrown on the valve spindle. As the opposite end of the lever is always heavier, the end on the spool-lifting lever need not bear on the bottom of the spool. The adjustment for wear is made by a fine thread and four flats on the spindle, so that very fine adjustments can be made.

In fig. 122 a distinct departure is made both in the construction of the valve and the lifting arrangement, and was introduced by the author in 1892.

It is well known that where a large engine is working at full power great difficulty is experienced from the exhaust valve fusing. To overcome this the head is made of 'cylinder liner' metal and attached to a steel spindle, the valve seat being also made of the same metal as the head. It is not good practice to arrange the exhaust valve in a loose box, especially on large engines. There is not only the difficulty of taking the box out, but there is a great tendency for the box to become distorted, owing to the comparatively large hole which must be in the box for the exhaust gases to escape in proportion to the sectional area of the box. To mitigate this a rib is placed in the centre of the opening.

The lower seat (as shown in fig. 122) admits of the water space being brought well up to the casing, and is at once a good mechanical job. The method of lifting is arranged so that in all positions of the lift the lifting die is at right-angles to the valve spindle. The valve spindle guide is loose, the joint on the under-side of the combustion chamber being a metallic one. Renewal of the guide or bushing is by this method considerably cheapened. This arrangement has been used with marked success by Messrs. Robey & Co. on their larger engines.

The pressure on the head of an exhaust valve in large engines amounts to about two tons, and the strain thrown on the worm gear and lifting mechanism is very great. To overcome this two exhaust valves have been used, one valve having twice the area of the other, the smaller valve being arranged with a 'lead' of the larger one.

An equilibrium exhaust valve arranged with one-half the

usual lift, and which would have the pressure equal to the difference between the two areas, is practical, and will, no doubt, be used on very large engines in the future.

Although valves working in a vertical position give good results, great difficulty is found in lubricating the spindle; and owing to the high temperature, and the amount of moisture contained in them, a leakage past the spindle into the engine-room is not unusual after twelve months' hard work. To overcome this one maker has arranged a hole in a spindle guide, leading to the air pipe, to allow the escaping exhaust to mingle with the incoming air.

Another means of overcoming this unpleasant leakage is to arrange a bowl on the valve spindle, surrounding the top part of the guide, which very effectually prevents the exhaust rushing down the spindle guide.

The diameter of the air and exhaust valves vary considerably with most makers; some on small and medium-sized engines use the same diameter for air as the exhaust, whilst others prefer the air valve larger than the exhaust. A common and good practice is to arrange the air valve for 100 and the exhaust for 80 feet per second.

CHAPTER XIII

GAS VALVE AND COCK

THE size of the gas inlet varies from 450 to 650 feet per second through the valve. There being no fixed rule for the diameter of the gas supply, the difficulty usually experienced is to get sufficient in; the same size is often used for three or four sizes of engines, the difference being made in the lift given to the valve and the size and number of holes in the air valve box.

A very neat form of gas cock and valve is shown at fig. 123. The plug is held in its place by three screws, two of them being used for determining the position of handle to 'open' and 'shut.' The gas valve can be readily taken out.

A good rule for the taper of the plug is to allow a taper of 1 inch in 8.

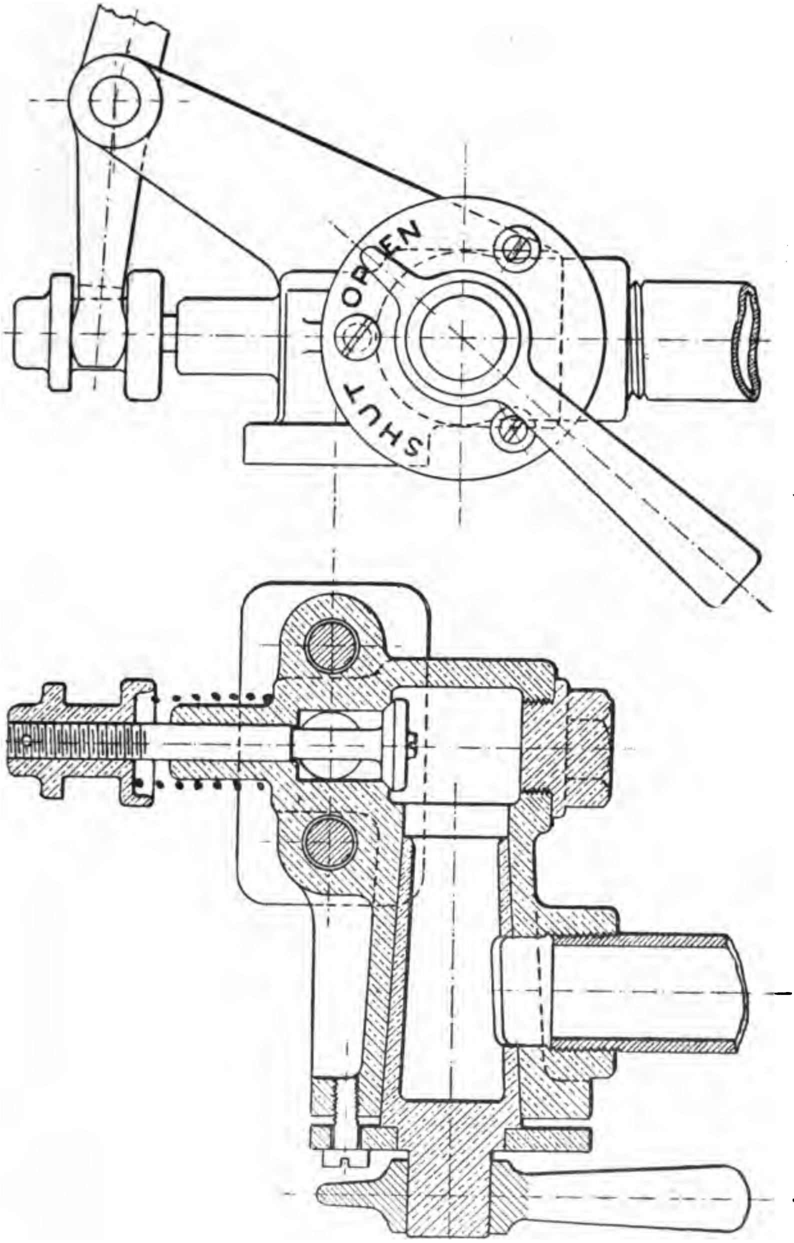


FIG. 123. — GAS VALVE AND COCK

CHAPTER XIV

STARTERS

SINCE Brayton used compressed air stored in a reservoir for starting purposes, which then, as now, was found unreliable owing to the difficulty of keeping up the pressure, the possibility of leakage, and also the reservoir being emptied before the engine was started, great strides have been made in the method of starting, and the development has gone on lines which may be classified as follows:

1. Pressure starter with a hand pump.
2. Low-pressure multiple impulse self-starter.
3. Low-pressure single impulse self-starter.
4. Low-pressure double acting.
5. High-pressure single impulse self-starter.
6. High-pressure single impulse with previous compression of air.
7. Steam from producer plant boiler.

Wells Brothers' Starter

The first application of the modern method of starter was introduced by Messrs Hamilton and Rollason, of the firm of Wells Brothers, in 1889. Fig. 124 is a part sectional elevation, fig. 125 end view, and fig. 126 a starting diagram.

At the extreme end of the combustion chamber is fixed a hand pump A fitted with a suction and delivery valve, the inlet of gas and air being through a three-way cock.

The action is as follows: The crank is placed on the firing stroke, and the timing valve kept closed by means of a catch. The combustion chamber being already filled with air, a proper charge of gas is pumped in, the three-way cock is then turned so as to admit air to the pump, which is then forced into the cylinder. The catch is released, and the charge ignites by means of the ordinary ignition tube.

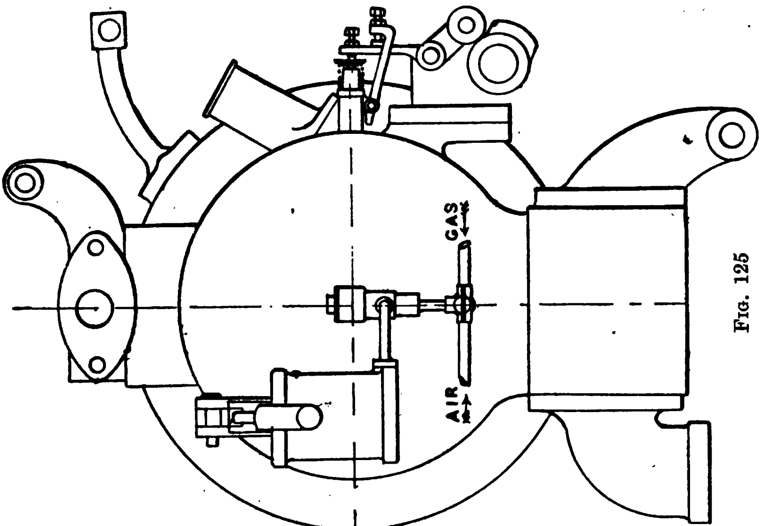


FIG. 125

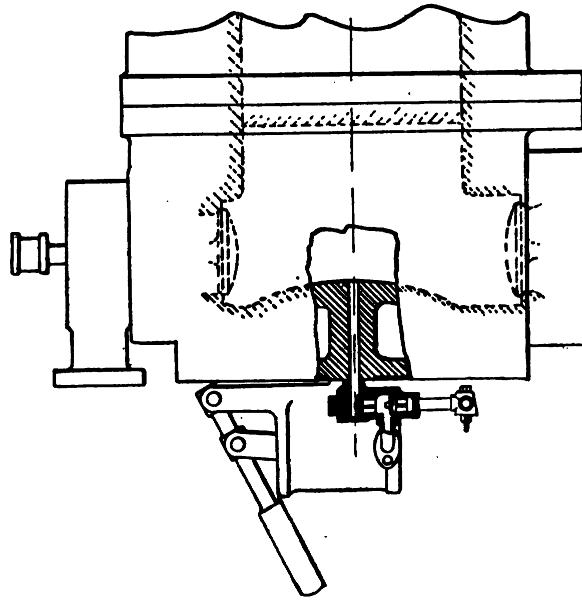


FIG. 124

FIGS. 124, 125.—WELLS BROTHERS' PRESSURE STARTER

In fig. 126 the starting is shown at 1, and the following ignitions (2, 3, and 4) take place in the same manner as when

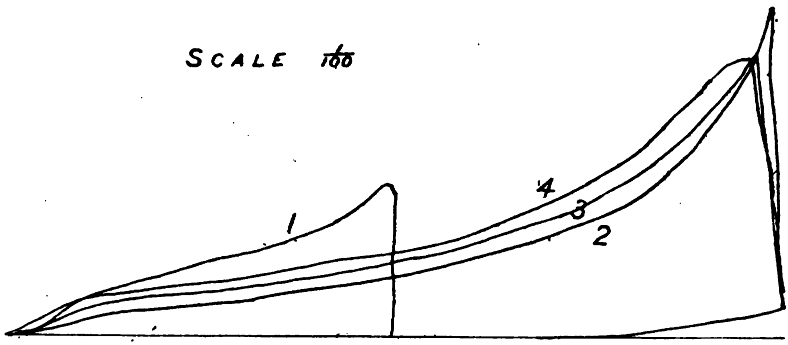


FIG. 126.—STARTING DIAGRAMS—WELLS BROTHERS

the engine is working, but as the compression is relieved the impulses are small. In practice this starter works well, and is exceedingly simple.

Lanchester Starter

A starter which has during the last few years made headway was introduced by Mr. Lanchester in 1890, some 600 of which are now at work.

Fig. 127 (No. 2) is a transverse section of a combustion chamber of an 11 × 18 inch stroke Robey engine fitted with a Lanchester self-starter. Fig. 128 is a facsimile of diagram taken from this engine.

A nozzle (1) opens to the explosion chamber of the engine, and connects it to a gas supply pipe by a valve (2). A cock (3) contains within it a valve (4) in the cylindrical space above the plug (5). The valve (4) rests upon the lower seat and has grooves or channels in it, so that while on the lower seat free communication is open between the compression space and the atmosphere. A pilot light (6) is lit when it is desired to start the engine, the crank is set over the centre and a little on the forward stroke (see fig. 128), and the gas valve (2) is opened by pressing the button (7). Gas then flows into the space as indi-

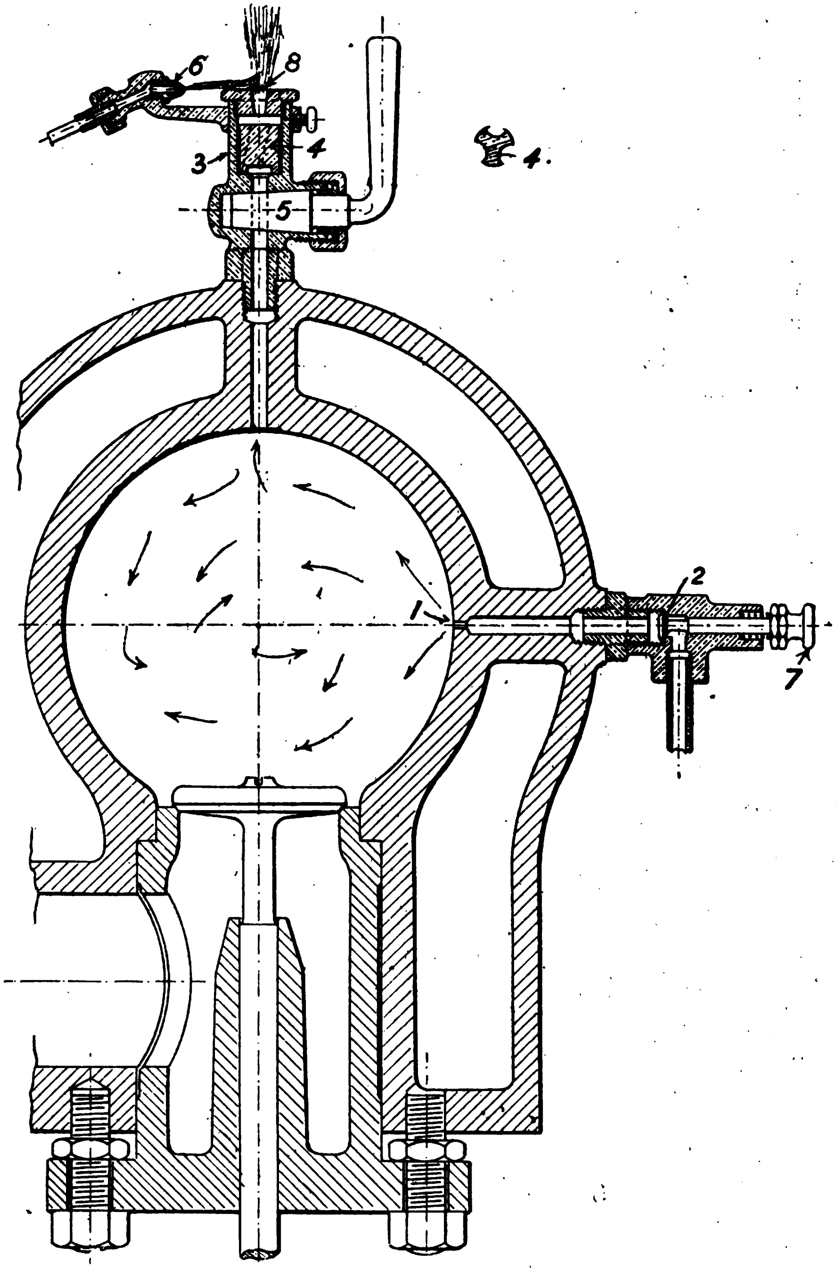


FIG. 127.—LANCHESTER MULTIPLE IMPULSE SELF-STARTER

cated by the arrows, and mixes with the air which was drawn in by the piston previous to stopping. Part of the air is displaced through the nozzle (8). At first air only passes out in this manner, but after a few seconds a mixture of gas and air is discharged; this mixture lights at the pilot light (6), and burns in the atmosphere more vigorously as the mixture becomes richer. Whenever it is rich enough in gas, which can be readily seen by the colour of the flame or by the characteristic roar made by it, the button (7) is released and the gas inlet shut off, and the cessation of flow allows the flame to strike back through the nozzle (8) into the compression space, and gives the starting impulse.

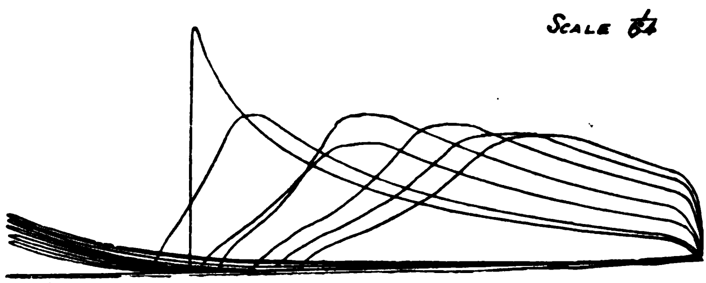


FIG. 128.—STARTING DIAGRAM—LANCHESTER

On the return stroke the products of combustion are expelled, on the next forward stroke a charge of gas is drawn in, and on the return stroke (compression stroke) the exhaust valve is held open almost the whole length of the stroke so that sufficient compression is attained to force the remaining charge up through valve (8), lighted by pilot light (6), and before the piston has moved appreciably on its next forward stroke another impulse is given. This is repeated every other revolution until sufficient speed has been attained to start against full compression. In this engine about seven explosions are sufficient. With some sizes one impulse is sufficient to start with the ordinary relieving cam.

One great advantage this starter has is the small amount of shock with starting and successive impulses, for it should

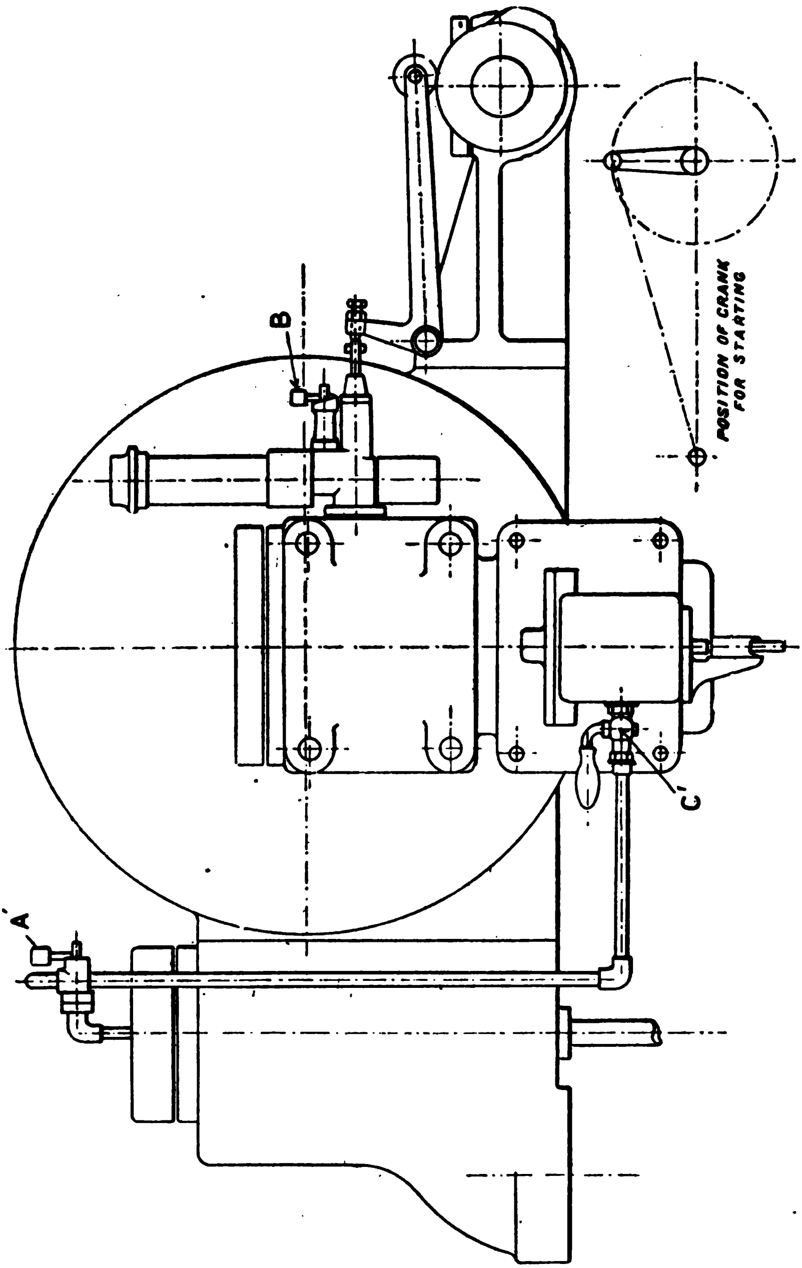


Fig. 131

Fig. 129

Figs. 129, 131.—'Stockport' self-starter

be borne in mind the danger attending a violent impulse when the engine is in a state of rest.

This gear is simplicity itself. It is only a question of pressing a button and the engine does the rest.

'Stockport' Starter

The distinguishing feature of the 'Stockport' self-starter is the automatic firing of the charge in the cylinder as soon as a combustible mixture has been reached.

Fig. 129 (No. 3) is an end elevation of an engine showing the gas connections from the main gas valve box to the inlet on the top of the exhaust valve.

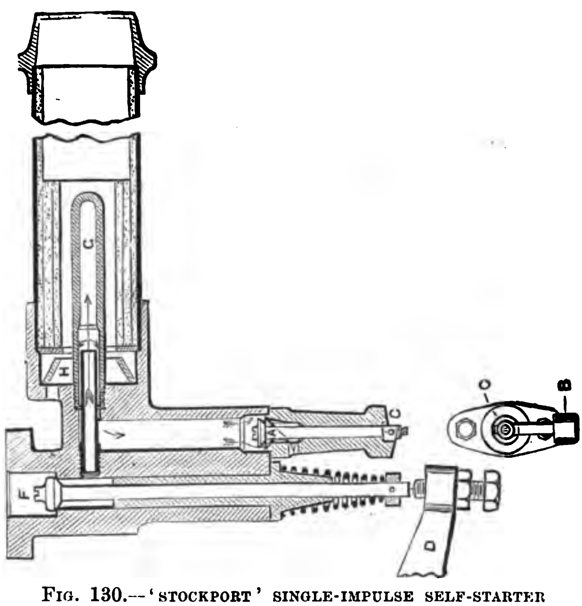


FIG. 130.—'STOCKPORT' SINGLE-IMPULSE SELF-STARTER

Fig. 130 is a section of the timing valve box and special relief valve for starter. Fig. 131 shows the necessary position of the crank when starting. Fig. 132 is a diagram of a self-starter and also a diagram from tube ignition, with relieving cam in action, of an engine having a cylinder 18 × 24 inches stroke.

The action is as follows. When the engine is on the impulse stroke, the ignition valve F is full open, and all the other valves closed. The roller on the exhaust lever is put in the position to gear with the relief cam, the gas supply is turned on slightly, so as to fill the gas bag, the escape valve A is opened by placing the small lever B in the notches marked 'To start,' the valve C′ is opened, and the gas coming in under pressure drives out a portion of the air inside the combustion chamber. The only aperture by which the air can escape is in the direction of the arrows by passing the timing valve, and then up the central ignition tube and down the space between inner and outer tubes—which is heated to incandescence—and

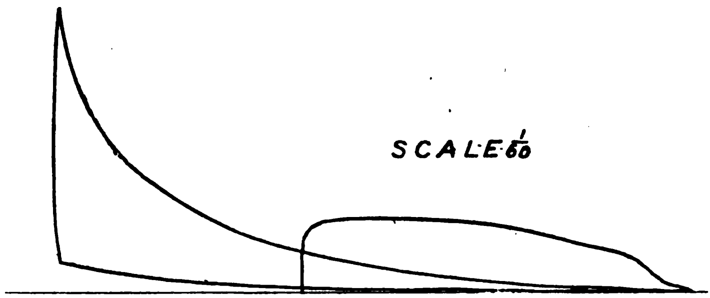


FIG. 132.—STARTING DIAGRAM—'STOCKPORT'

through the valve A to the atmosphere. In one minute this gas is in sufficient quantity to form an ignitible mixture; the velocity is such that the charge is fired by the ignition tube.

After the engine has made about six explosions (see fig. 132) the valves A′, B, and C′ must be closed, the gas cock on the gas bag opened full, the exhaust roller on the exhaust lever be moved so that it comes into gear with the main exhaust cam, and the engine will be in full working order.

This starter is simple and effective.

Norris's Starter

Fig. 133 (No. 4) is a facsimile of a diagram taken from an 18 B.H.P. Robey engine fitted with the author's 'impulse every

revolution starter' in 1891. In this arrangement a double set of cams are necessary so that the engine has an impulse every revolution, until sufficient speed has been attained to fire with it from the tube ; a pilot light is arranged at the back in close proximity to a small touch-hole.

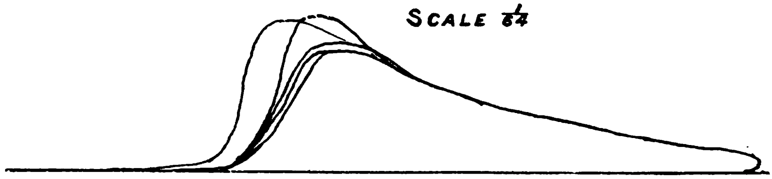


FIG. 133.—STARTING DIAGRAM—NORRIS

To start the engine the pilot light is lit, the touch-hole opened, the flywheel moved by hand or lever, and gas and air is drawn in for about one-third of the stroke, the flame is drawn into the cylinder through the touch-hole, and an impulse is given; on the return stroke the products of combustion are expelled. The next forward stroke gas and air is drawn in and another impulse given which is continued until sufficient velocity has been attained to start in the ordinary way. It makes little or no difference if the touch-hole is closed with a spindle or not. The amount of explosion escaping is practically *nil.*

The complication necessary in using this method prohibits its use.

Clerk-Lanchester High-pressure Starter

In 1891 Mr. Dugald Clerk invented a high-pressure starter, and used the Lanchester igniter in conjunction with it.

Fig. 134 (No. 5) is a sectional elevation of the starter, showing its connection to the combustion chamber of a Robey engine having a cylinder 14 × 21 inches stroke.

Fig. 135 is a diagram taken from this engine, showing a maximum pressure of 200 lbs. above the atmosphere, and an average pressure of 38·3 lbs. per square inch.

To start the engine the check valve A is released and the crank is placed slightly on the firing stroke (say 1½ inch), the pilot

light B for the Lanchester igniter is lighted, and the gas cock C opened, the gas mingles with the air in the cylindrical chamber D and combustion chamber E, and flows out through the valve F, and as soon as an explosive mixture is formed, which is in about fifteen seconds, the roaring of the burning mixture at G

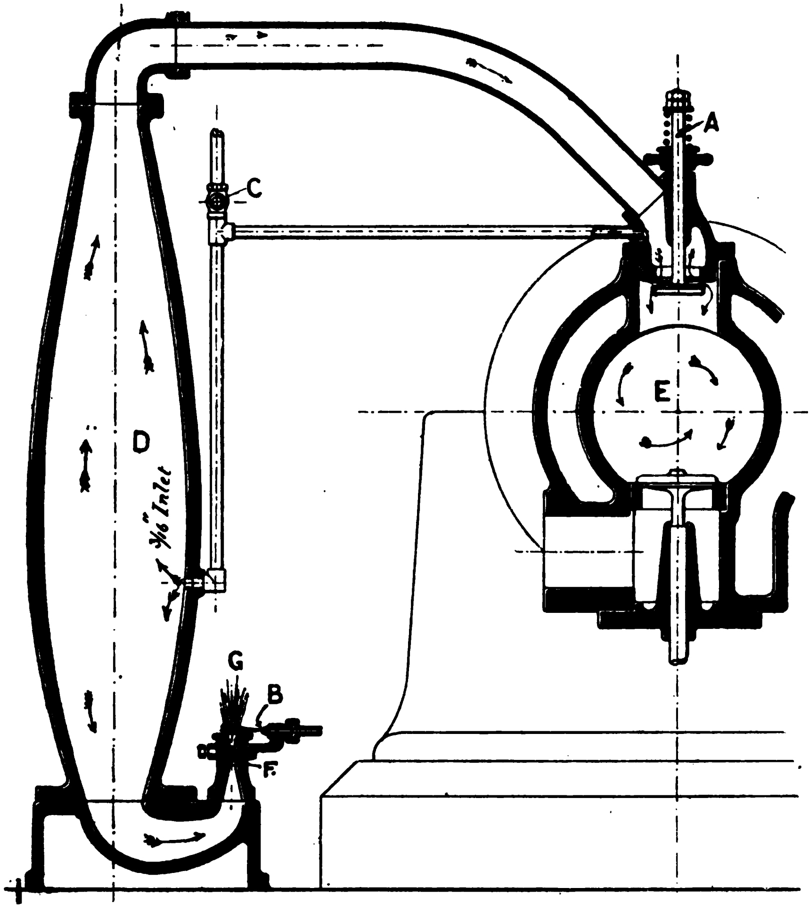


FIG. 134. CLERK-LANCHESTER HIGH-PRESSURE STARTER

indicates that the charge in the cylinder is of the right mixture. The gas cock C is shut off, and the flame shoots back and closes the small valve F. The flame so produced under atmospheric

pressure fills the chamber D, and forces the gas past the check valve A into the combustion chamber, and compresses the charge to 30 lbs. per square inch, and then explodes. The mixture is therefore compressed into the combustion chamber by a preliminary explosion. To prevent the starting impulse bursting the ignition tube—when worn, or when using a porcelain tube—the igniter is thrown out of gear until the engine has received the full force of the starting inpulse.

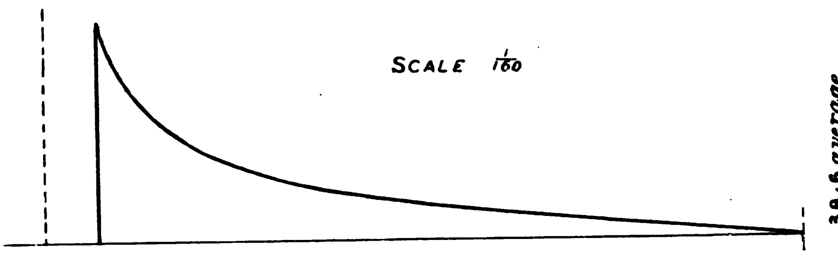


FIG. 135.—STARTING DIAGRAM—CLERK-LANCHESTER

It is possible to vary the force of the starting impulse by arranging the length of the connected pipe, so that a less violent explosion may be obtained. It is also possible to time the colour of the mixture issuing from G, so that the preliminary impulse puts the engine into motion previous to the main impulse being given. When the check valve A is left closed through carelessness, the greatest possible pressure obtainable is only 30 lbs. per square inch.

The gas required for starting impulse	= 700	cubic	inches
Capacity of the starter	= 2,732	,,	,,
Capacity of the combustion chamber	= 1,628	,,	,,

This starter is now the exclusive right of Messrs. Crossley Brothers, and is used with a long horizontal pipe, and hand pump to charge, the starting impulse being less powerful than the above.

Fielding's Starter

Fig. 136 (No. 6) is a sectional elevation of a 100 I.H.P. Fielding engine, fitted with starting gear, but without the air chamber, which may be fixed in any convenient position.

Fig. 137 is a facsimile of a starting diagram taken from a 12 H.P. NOM. Fielding engine. Fig. 138 is an external end elevation showing the air reservoir A fitted with a hand pump,

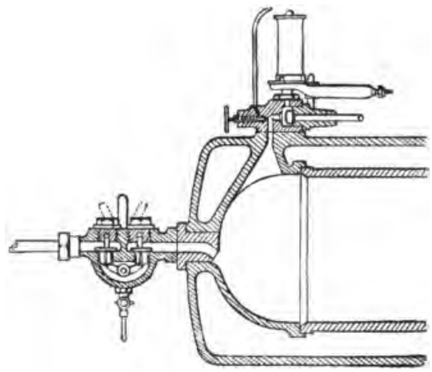


FIG. 136.—100 I.H.P. FIELDING ENGINE, SHOWING STARTING GEAR

which is used for charging the reservoir with air at 60 lbs. per square inch when starting the engine for the first time.

In this method of starting compressed air is stored in a reservoir, by the action of the engine, at about 60 lbs. per square inch, the crank is placed at an angle of 15°, one of the valves is opened by a lever, the gas being admitted much in the same

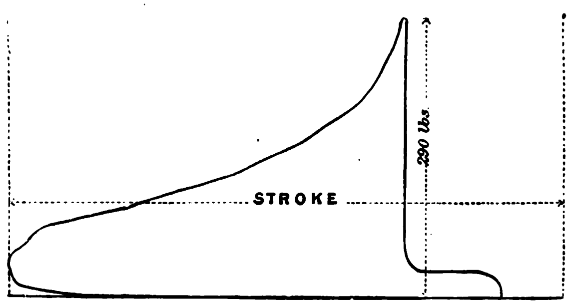


FIG. 137.—STARTING DIAGRAM FROM 12 H.P. NOM. FIELDING ENGINE

Scale, 150 lbs. per square inch. Average pressure, 99·5 lbs. per square inch

manner as in the Lanchester starter; on entering, the gas is directed downwards so as to drive out the air, which escapes by the igniting port, a light is applied at the end, and the presence

of a flame issuing from the pipe shows that the cylinder is fully charged with gas—but not with an explosive mixture.

The compressed air is, by the reversal of a handle, then in-

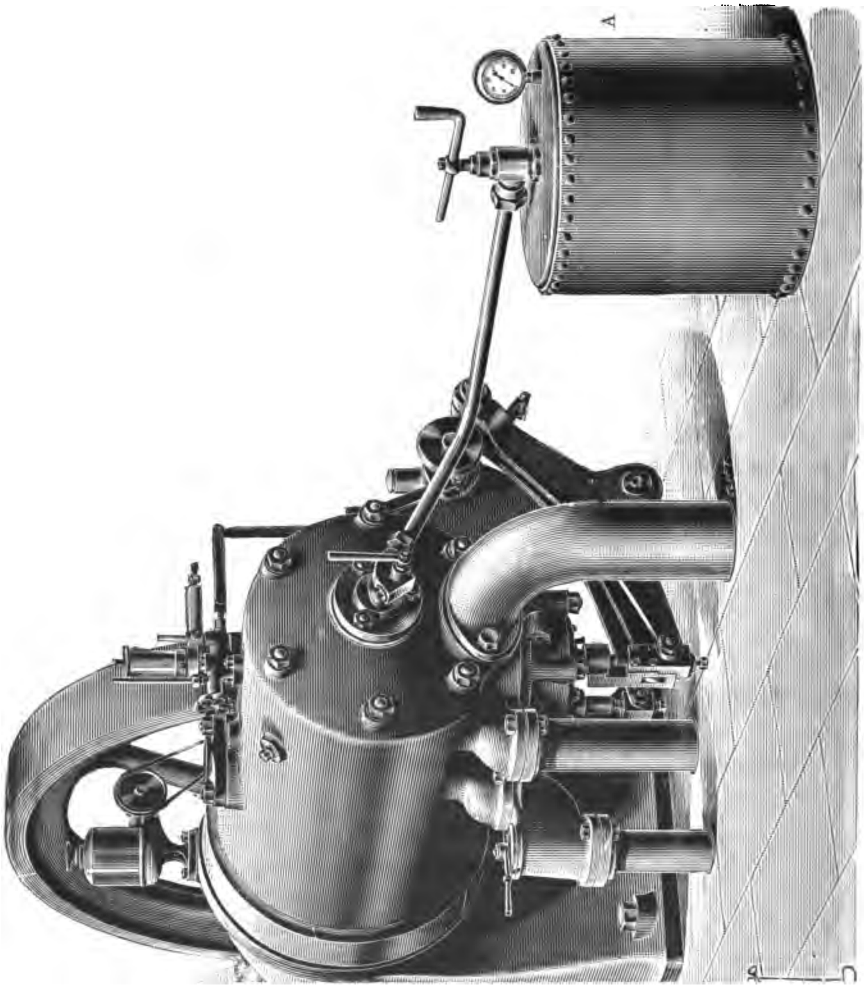


FIG. 138.- FIELDING STARTER

troduced into the cylinder, where it mingles with the gas, forming an explosive mixture under a pressure of 50 or 60 lbs. per square inch, and is automatically ignited by the ordinary

Bunsen heated tube at the moment a suitable mixture is formed. The impulse is indicated by the diagram, fig. 137.

By this method a very powerful impulse is obtained, something like 300 lbs. above atmosphere, and with an average pressure of about 100 lbs. per square inch.

It is very questionable if the advantage gained by so powerful an impulse is good practice. The fact that the engine is at rest and the inertia of the moving parts being considerable, shows very clearly that a considerable strain must necessarily be thrown suddenly on the whole of the moving parts, tending in no small degree to damage the bearings and interfere with the keys in the flywheels.

The makers guarantee this starter to be efficient against two-thirds of the full load.

With a lower air pressure, and having the driving belt on a loose pulley and depending upon a number of low compression impulses with the ordinary relieving cam in action, the shock would be reduced to a very large extent.

Tangyes' Starter

The starter used by Messrs. Tangyes on their engine is of the pressure type; a hand pump is attached to the combustion chamber. The crank is placed at an angle of 30° over the dead centre and held there by means of a catch. The ignition valve is closed by inserting a wedge between the lever and the igniting valve spindle; thirty or forty charges of gas and air are pumped into the combustion chamber, according to the size of the engine, and a pressure of about 10 lbs. attained. The ignition valve is then opened and the compressed charge rushes up the ignition tube and is fired; if the charge is correct the pressure forces the catch out of position, and a start is effected. The following impulses are obtained with the ordinary timing valve and relieving cam in action.

This system only holds good when there is no leakage past the piston or the valves. In starting large engines, or where it is required to start several engines at once, Messrs. Tangyes now use a mild steel reservoir, into which the explosive charge

is pumped to a pressure of 80 lbs. and from which the cylinders are charged.

Dowson's Starter No. 7

When Dowson gas is used, the steam generated in the small boiler used in the manufacture of his gas is utilised for starting the engine. Usually the steam pressure is about 60 lbs. per square inch. To start the engine, the crank is placed over the dead centre on the firing stroke, and steam is admitted until the piston has nearly reached the end of the out-stroke. Where a number of impulses is necessary a special cam is arranged to admit steam for several alternate revolutions.

CHAPTER XV

THE BUNSEN BURNER

FIG. 139 is a part sectional elevation, showing a neat form of Bunsen burner used for heating the ignition tube by Messrs.

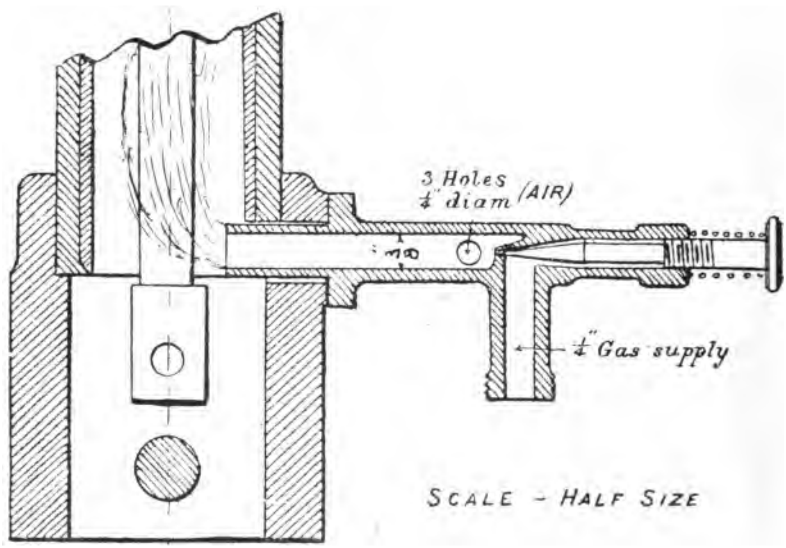


FIG. 139.– BUNSEN BURNER—CROSSLEY'S

Crossley Brothers and other makers of gas engines. The gas

issues from a small jet at the base of the gas supply, and mixes with air which is drawn in through three openings in the tube; it then burns at the end of the tube with a non-luminous flame. The existence of this flame in its ordinary condition depends upon two main causes; first, upon the fact that in the immediate neighbourhood of a jet of gas issuing from a small orifice there is a reduction of pressure; and, second, upon the relation between the velocity at which the gases pass up the tube and the rate of propagation of combustion in the mixture of air and coal gas downwards. Upon the first of these causes depends the entrance of air into the 'air-holes' of the tube, and upon the second depends the continuance of the flame in its position upon the end of the tube. The consumption of gas equals 3½ to 4 cubic feet per hour. The method of adjusting the gas supply is simple and effective.

Temperature in Different Parts of a Bunsen Flame (Gas Consumption 6 Cubic Feet per Hour)

Professor Vivian B. Lewes

—	With Blue Inner Cone	With Greenish Inner Cone
	Fahr. Cent.	Fahr. Cent.
Tip of inner cone	1,994° = 1,090°	2,867° = 1,575°
Centre of outer cone	2,791° = 1,533°	2,966° = 1,630°
Tip of outer cone	2,147° = 1,175°	2,813° = 1,545°
Side of outer cone level with tip of inner cone .	2,431° = 1,333°	2,752° = 1,511°
Proportion of mixture 1 volume of gas to . .	2·27 air	3·37 air

CHAPTER XVI

AUTOMATIC TUBE IGNITION

The method of firing the charge in the combustion chamber by means of an incandescent tube is now common to all makes of gas engines, the slide with its open flame having been abandoned. The compression gas engine by Mr. James Atkinson in 1879 was the first to work with a hot tube ignition practically the same as that used at the present day. An igniting

tube of wrought iron or ordinary gas pipe, open at its lower end to a hole drilled through the cylinder wall, was used in his Differential engine exhibited at the Inventions Exhibition in 1885. Early in 1881 Mr. William Watson patented various methods of igniting gases by applying heat externally to some part of the vessel, chamber, or tube in which the gases to be exploded are contained; in fact, the timing valve and bulb as we now have it is only a slight modification of Watson's method. Yet it was not until 1888 that the makers of the 'Otto' engine finally decided to substitute the tube ignition for the open flame and slide, and it is a disputed point even now amongst the best authorities on the gas engine whether the tube should be used with its opening always free to the combustion chamber, or whether a timing valve should be used, closing the opening during a certain portion of the stroke. The author holds the opinion very strongly that this valve neither conduces to economy nor power, but would point out that automatic tube ignition needs good governing arrangements, as it detects any defects in the governor very quickly, and a timing valve may hide any defects in this direction.

The Robey Automatic Tube Igniter

Fig. 140 is a sectional elevation, and fig. 141 an end view of an angular automatic tube igniter. A is the combustion chamber, B the igniter passage, C the Bunsen burner. The advantage gained by this arrangement is that the flame naturally surrounds the tube. The igniter passage is shortened, and ignition can be timed without disconnecting any part, by simply turning the Bunsen burner on the pivot D.

The Fielding Automatic Tube Igniter

Fig. 142 is a sectional elevation of a vertical automatic tube igniter introduced by Mr. J. Fielding in 1890.

The special feature in this arrangement is that the Bunsen

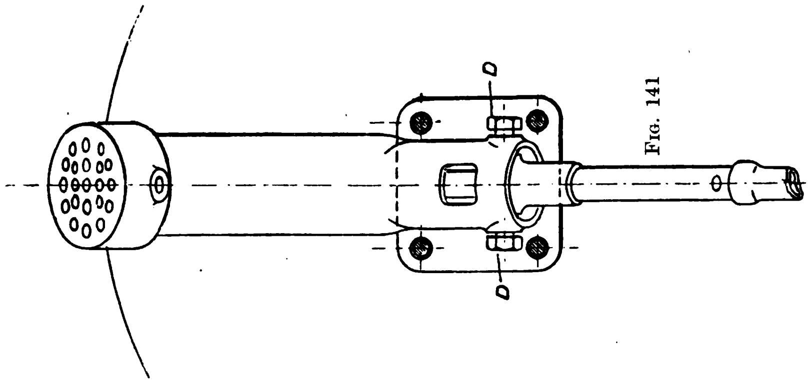


FIG. 141

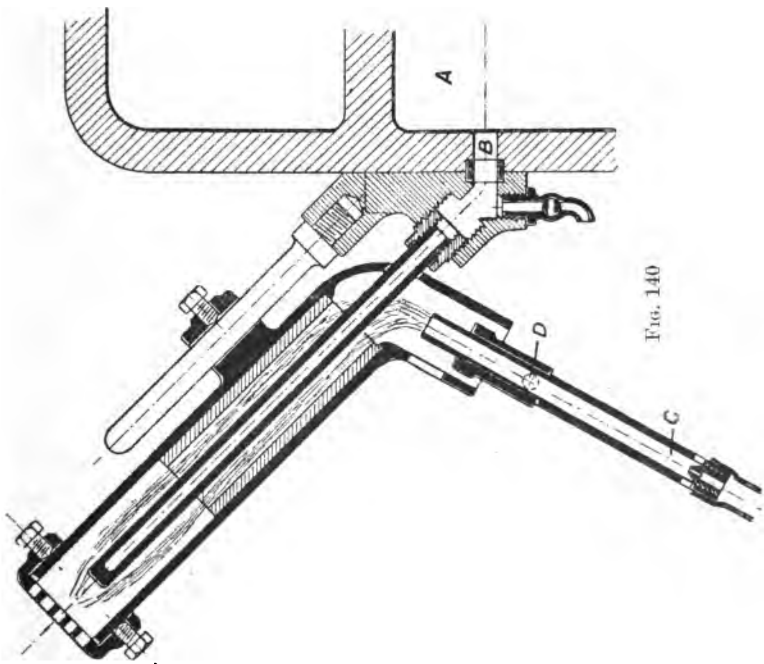


FIG. 140

FIGS. 140, 141.—AUTOMATIC TUBE IGNITER—ROBEY

burner used is arranged so that the mixture of gas and air issues laterally towards the centre from an annular groove surrounding the tube, thus impinging directly upon it. Air is supplied in suitable proportions below and above the flame to ensure

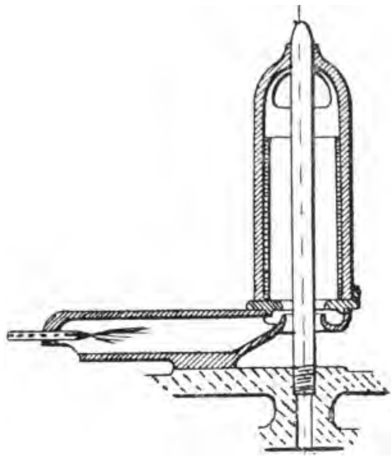


FIG. 142.—AUTOMATIC TUBE IGNITER—FIELDING

perfect combustion; the usual chimney lined with non-conducting material is provided above the burner, which is arranged so that falling flakes or scale from the tube may drop clear without danger of clogging up the gas or air passages.

CHAPTER XVII

IGNITION TUBES

THE life of an ignition tube depends upon the material it is made of, but varies greatly according to the usage it receives. This life is shortened by intense heating, with sudden changes in pressure and temperature produced by the inrush of comparatively cool gases, whereas gradual changes tend to longevity. It is found that wrought-iron tubes deteriorate rapidly owing to high pressure within the cylinder at the moment of ignition. The thin tube, raised to white heat, is only exposed to the

atmospheric pressure outside, and the great pressure suddenly produced within has a tendency to burst it, and care should be taken that it is not over-heated or softened too much. It is found that the fresh mixture of air and gas when introduced cools the inner surface, and that it is necessary to use thin tubes, since thick ones are not so easily raised by a flame outside to such a temperature that even poor gases may be readily ignited by contact with their inner surfaces.

Ignition tubes made of ¼-inch steam tubing will give very satisfactory results without a timing valve when using an angle chimney. Here part of the mixture is gradually compressed into the tube under the most favourable conditions. The tube is constantly open to the cylinder, and the length of the heated part of the tube is so adjusted that the small portion of the explosive mixture gradually forced into it becomes ignited, and has just time to fire the main charge in the cylinder at the proper instant. Ordinary wrought-iron gas tubing is used, though the life of such a tube is very uncertain. Numerous so-called alloys are used, and give fairly good results.

The 'Wellington' tube, when carefully handled, gives very good results. This tube consists of specially combined silica of earths exposed to certain treatment in drying and baking.

The heating of this tube is very quick, and with care the life is some years. At the same time the heat of the tube cannot equal in intensity that of the electric spark or voltaic arc, which is near the temperature of volatilisation of the insulated points between which the arc passes. Hence the continuous stream of electric sparks, which is practically unaffected by ordinary currents of cold gas and air, affords the surest and most powerful means of igniting a poor gaseous mixture under high pressure. For practical everyday use the disadvantages, however, more than counterbalance the advantages, and even when using producer gas from coke, a Bunsen burner can be arranged to use the same gas, and give very satisfactory results.

CHAPTER XVIII

TIMING VALVES

THE more control the timing valve has over ignition the less 'lead' is required, so that the tube should be heated as low down as possible; and to ensure the immediate contact of the charge with the heated part of the tube, a bulb is attached, into which the inert gases retained from the previous cycle are forced. If the clearance leading to the valve is long, a bulb is connected with the passage as near the tube as possible, so that the gases in the clearance space may be partly forced into it, as well as to give the fresh charge greater tube space. Should the valve require much 'lead' to fire the charge on the dead centre, its control over the ignition will be lessened. Some timing valves are not made air-tight—that is to say, a small groove is made in the valve face causing a slight escape at each stroke of the engine, just sufficient to draw by induction some of the products of combustion out of the ignition tube. For this purpose a separate shifting-valve is used.

Crossley's Timing Arrangement

Fig. 143 is a side elevation, fig, 144 front elevation, and fig. 145 a plan of timing arrangement used by Messrs. Crossley Brothers.

The 'lead' in this type of timer is very small, the valve opening very rapidly. During the compression stroke the communication between the combustion chamber and hot tube is closed, and inert gases are allowed to escape to the atmosphere.

The end of spindle acts as a valve, and is responsible for the correct time of firing. This is a very important detail. The stroke of the valve is $\frac{5}{16}$ inch, and when wear and tear

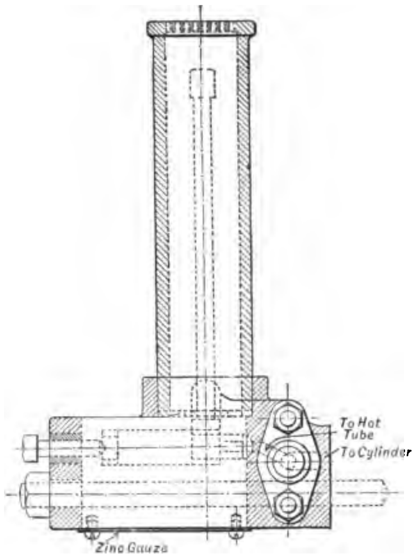


Fig. 143.—SIDE ELEVATION

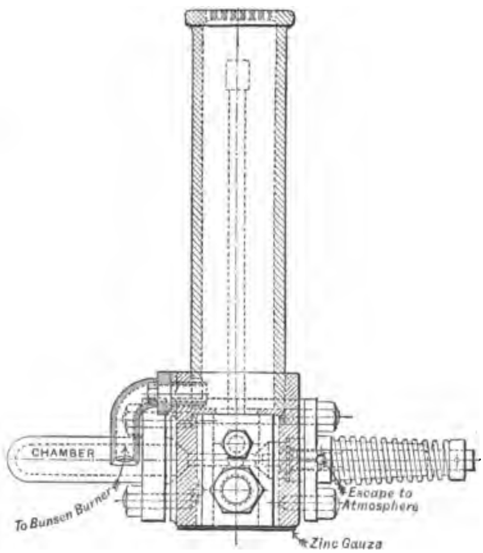


Fig. 144.—FRONT ELEVATION

Figs. 143, 144.—TIMING ARRANGEMENT—CROSSLEY'S

of cam, roller, &c., reduces the stroke to $\frac{1}{4}$ inch the worn part should be renewed. If this precaution is neglected the engine may reverse at starting. The ignition valve and guide are made of phosphor bronze, and are easily removed for grinding the valve in.

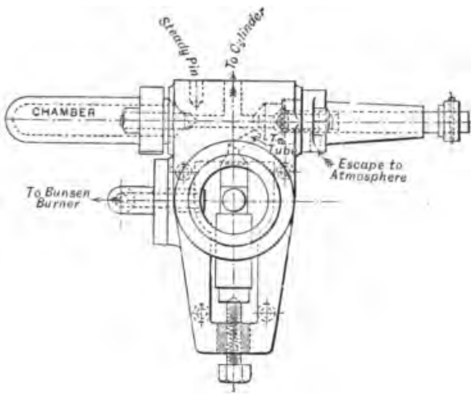


FIG. 145.—TIMING ARRANGEMENT—CROSSLEY'S

The method of taking the ignition tube out for renewal is simple, and when the ignition valve is placed vertically it acts well.

'Stockport' Timing Valve

Fig. 146 is a sectional elevation of the timing arrangement combined with a self-starter used by Messrs. Andrews on their engines, F being the timing valve and A the valve used for the self-starter, G ignition tube, D lever for operating timing valve, H mantle for enveloping flame round tube. The ignition tube employed is a small one, and is arranged so that the gas and air mixture can at each ignition blow out some of the products of combustion remaining from the last ignition. This is effected through the small annular passage for the air and gas mixture between the inner and outer tube, as shown in the section. The valve F is not air-tight, a small groove being made in its face so that there is a slight escape at each

suction stroke of the piston, just sufficient to cause some of the products of combustion to be drawn out of the ignition tube. For engines of large powers two complete timing valves are arranged in one box, having one common passage leading

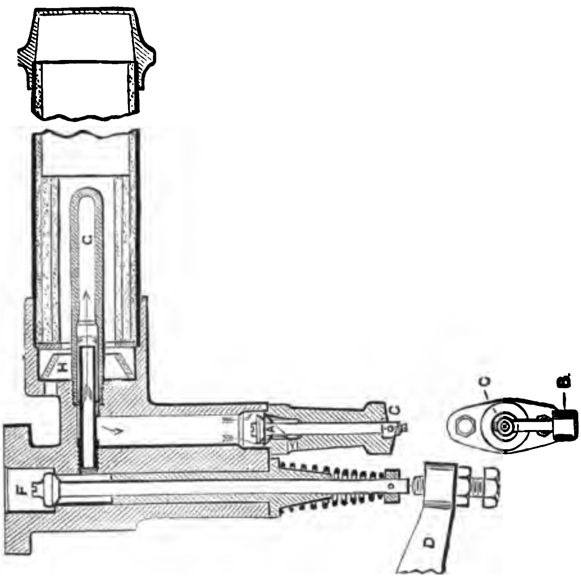


FIG. 146.—TIMING VALVE (STOCKPORT)

to the combustion chamber. Ignition is arranged in duplicate so that in the event of accident to ignition tube—say, by bursting—one timing valve may be thrown out of gear of cam, and the other valve brought into action. This can be done automatically, the resultant force from the broken tube being made to act on a vane placed at the top of the chimney. This firm's ordinary timing valve works well, and the ' lead ' can be regulated at will.

Tangyes' Timing Valve

Fig. 147 is an external elevation, and fig. 148 a sectional plan of the timing arrangement fitted to Messrs. Tangyes' engines.

A is the combustion chamber, and B the timing valve held

hard on to the seat B^1 by the spring C. It will be seen that the valve is made in two pieces, the object of which is to pro-

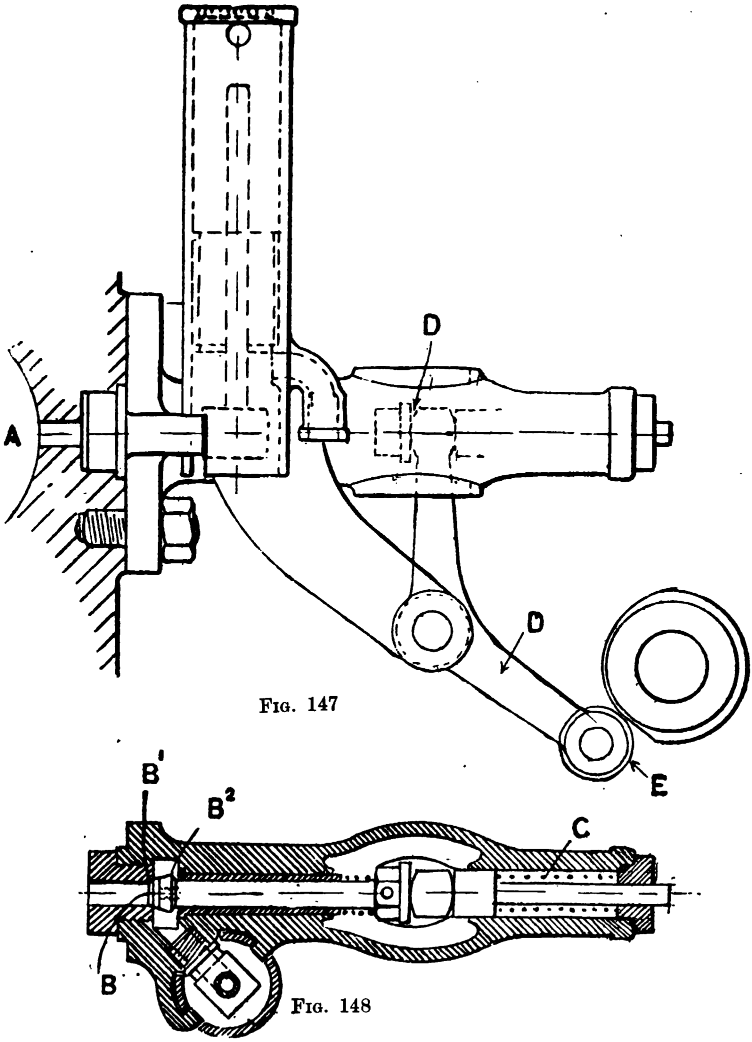


FIG. 147

FIG. 148

FIGS. 147, 148.—TIMING VALVE—TANGYES'

vide an arrangement so that a wedge inserted at D when starting, forcing the valve hard on to seat B^1 and being suddenly

withdrawn, admits the compressed charge into the igniter tube. The valve B^2 prevents the escaping explosion by forcing the spindle on to its seat and the roller E away from its cam.

The double-seated valve spindle is made of phosphor bronze tipped with tool steel. The passage connecting combustion chamber with point of incandescence being short and direct is a very commendable point.

Robey Timing Valve

Fig. 149 is an end elevation, and fig. 150 a sectional elevation of a timing valve designed by the author in 1890, having for its main feature the possibility of adjusting the 'lead' to suit high or low speeds whilst the engine is in motion, and retaining the value of direct ignition of the charge.

A is the combustion chamber, B the passage leading to hot tube, C a double-seated valve spindle held on first seat by spring D, E the lever operated from any convenient part of engine, F the spool provided with a square head, and G the Bunsen burner arranged to impinge on hot tube below the reduced part of the chimney. During the greater portion of the compression stroke the valve C is closed, and the time of opening is regulated to suit the amount of compression and speed of the engine, but is allowed to remain open during the firing and exhausting stroke, the partial vacuum during the exhausting stroke being sufficient to exhaust ignition tube so as not to interfere with the next ignition.

As far as timing valves go, this arrangement works well; the valve can be turned round on its seat to ensure a good face without disconnecting the spring used for closing it.

CHAPTER XIX

ANTI-FLUCTUATING GAS BAGS

THE suction of gas from the main pipe and then through the meter during the ordinary cycle of operations is necessarily intermittent, which is greatly intensified when the load on the

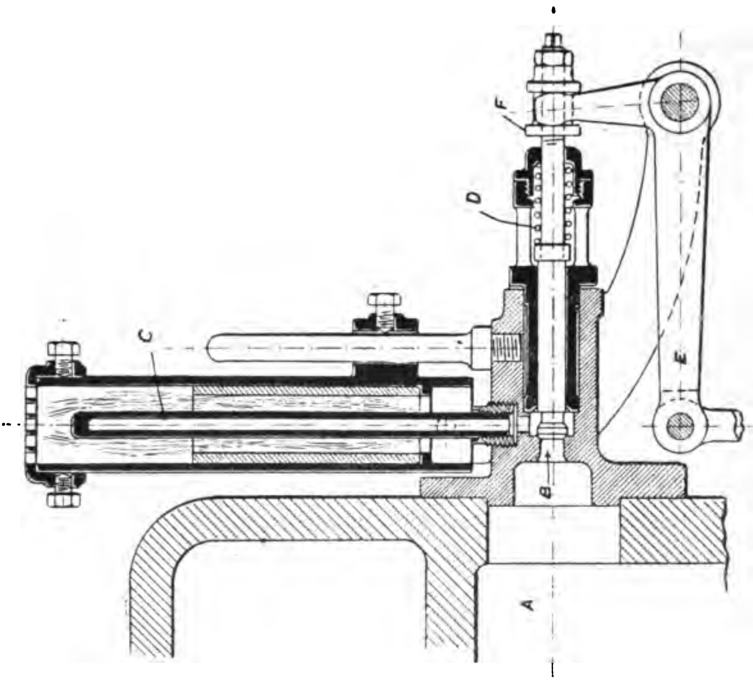


Fig. 150

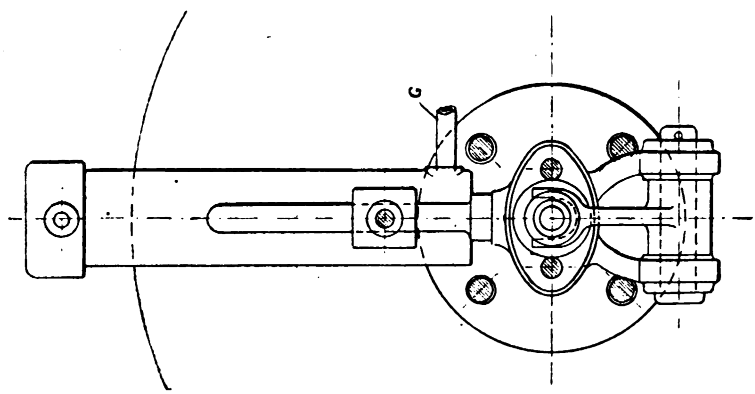


Fig. 149

Figs. 149, 150.—Timing valve (Robey)

engine is very varied. If no provision were made, the users of gas from the same main would find their supplies varying in

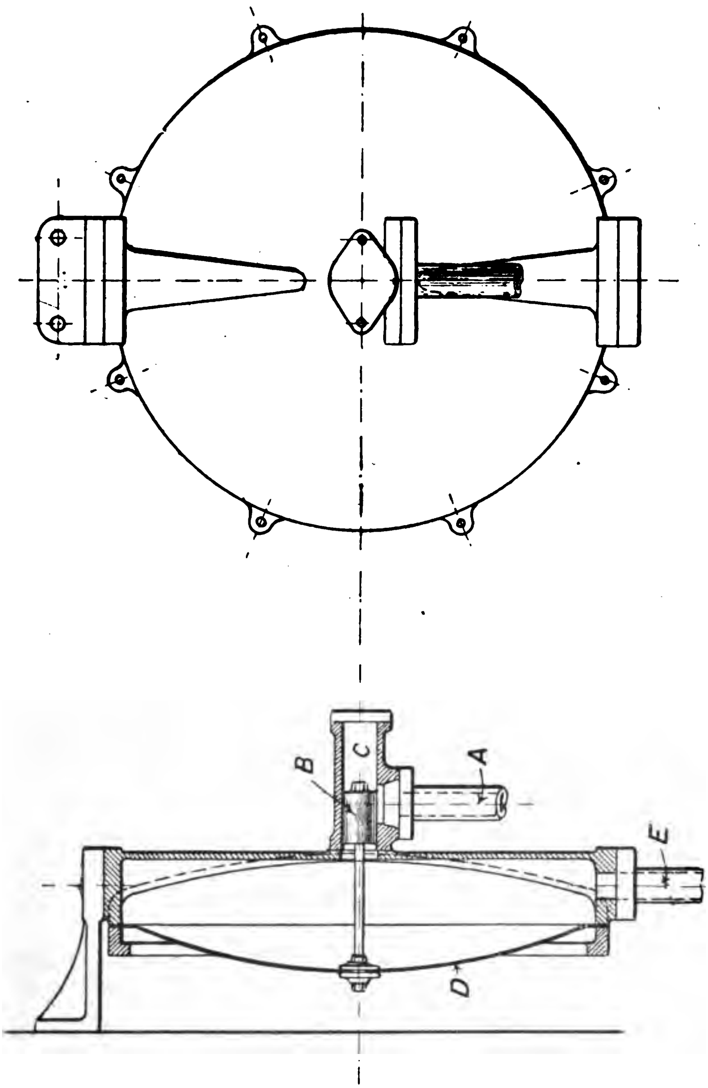


Fig. 152

Fig. 151

Figs. 151, 152.—Anti-fluctuating gas bag (Crossleys')

the same ratio, but to provide for this a reservoir is placed between the meter and engine, in part or wholly made of india-

rubber, so that the rubber being distended in filling, relieves these sudden demands upon the meter. An ordinary rubber bag has, however, been found insufficient to ensure complete steadiness in the surrounding mains, and anti-fluctuators, in fact as in name, have been designed, and are fixed between the meter and the gas bag, or on the gas bag and forming part of it.

Fig. 151 is a sectional elevation, and fig. 152 an external elevation of an anti-fluctuating gas bag used by Messrs. Crossley Brothers. A is the gas inlet terminating in a slot, B is the cut-off valve made to fit slack in the cylinder C, D the indiarubber or canvas and rubber, and E the outlet to gas cock on the engine.

The action is as follows: The bag being filled, the rubber shown inflated, and the cut-off valve B closing the gas inlet, the engine can then draw a charge which depresses the rubber and moves the cut-off valve over the slot, again allowing the bag to be recharged by the ordinary pressure from the main. By drawing from the bag with the gas supply pipe practically shut off from the main in the neighbourhood of the meter, pulsation of lights is to a large extent avoided. There is, however, a tendency for this cut-off valve to stick if the quality of the gas is not good, and if the engine is hard worked it becomes a difficult matter to keep the bag supplied with gas, and pulsation of lights is noticeable. In all cases a large gas bag should be used, to assist the anti-pulsator as much as possible.

With producer gas anti-fluctuators are unnecessary.

The Robey Anti-fluctuator

Fig. 153 is a sectional elevation, and fig. 154 a sectional front view of an anti-fluctuator used by Messrs. Robey & Co. and designed by the author.

It will be seen that two rubber sides are used, connected by toggle levers to a vertical rod, on the end of which is attached the cut-off valve. A is the gas inlet, arranged to enter valve box chamber by a number of port-holes; B the cut-off

valve, which is a slack fit in the bush C; D D' the rubbers or canvas and rubber, and E the outlet to gas cock on engine.

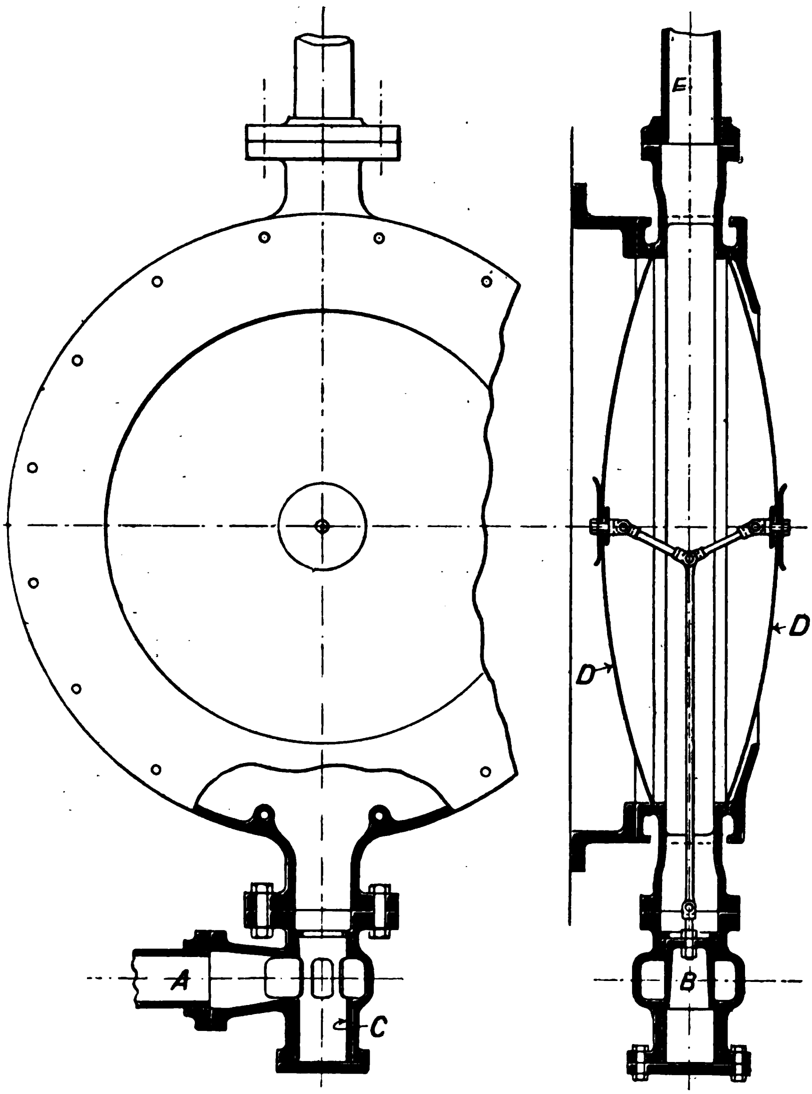


FIG. 154 FIG. 153

FIGS. 153, 154.—ANTI-FLUCTUATOR (ROBEY)

The action is as follows: The bag is shown filled with the

rubbers inflated and the cut-off valve B in its top position with the gas supply shut off; when a charge is taken by the engine the rubbers are depressed, the cut-off valve falls, uncovering the port-holes and allowing the gas to flow in and inflate the bag again.

By arranging the cut-off valve in a vertical position in combination with two rubbers a very sensitive cut off can be obtained, and the difficulty experienced with the cut-off valve tending to stick or wear oval is overcome.

CHAPTER XX

CYLINDER LUBRICATION

One small but by no means unimportant item of gas engine construction is the method used for lubricating the cylinder, this being the chief factor which checked the development of gas engines thirty-five years ago, as the property of mineral oils to withstand high temperatures was then unknown. The steam engine, with its low pressures and slow speeds, needed very little care in this direction, and the gas engine was presumed to be the same; and it seems almost impossible to realise that at this day, when the importance of suitable oils being used in the cylinder has been insisted upon by the foremost engine makers, that so many engines are completely ruined for the sake of a few pence per gallon in the cost of oil. 'The reason for using oil at all is to lubricate; therefore use the oil that lubricates most.' Professor Thurston, in his admirable 'Treatise on Friction and Lost Work in Machinery and Mill Work,' well says: 'The price of an oil is usually of little importance in comparison with its friction-reducing power.'

Fig. 155 is a section of a cylinder lubricator introduced by Messrs. Crossley Brothers on their earliest engines, and used by them and most of the other engine builders at the present time. In the earlier engines this lubricator was arranged with two pipes—one to supply oil to the cylinder, and the other to the slide; and there is no doubt that this method of lubricating the slide added greatly to the success of the earlier engines.

Referring to fig. 155, the pulley A is driven by an endless belt from the side shaft. On the spindle B a crank C is attached arranged to carry a wire D, which in its travel wipes the oil it has lifted from the reservoir on to a fixed pin E situated over the space leading to the oil tube. The pulley is driven slowly, and as it rotates it carries the wire round the pin E, alternately dipping into the oil and wiping it off on the fixed pin, whence it runs into the trough F and down the pipe G to the cylinder; it will be seen that the amount of oil carried by the wire must vary with the amount in the reservoir.

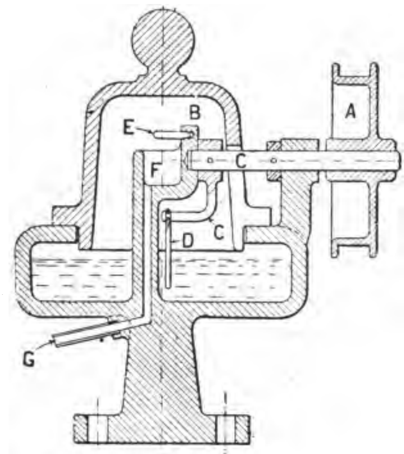


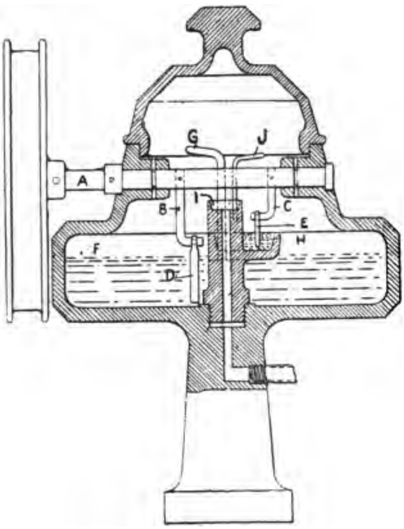
FIG. 155.—CYLINDER LUBRICATOR (CROSSLEYS')

This alternate dipping into an oil well and discharging a variable amount of oil to the cylinder does not distribute the oil evenly in all circumstances, owing to the continual variation in the level of the oil in the reservoir.

It was with the object of obtaining a constant feed that the author designed the duplicate dip wire used by Robey & Co., the special feature of which is that one carrier simply serves to keep full to overflowing a second reservoir, from which the oil is taken to the cylinder at a uniform rate, irrespective of the level of the oil in the main reservoir.

The Robey Lubricator

Fig. 156 is a sectional elevation, and fig. 157 a plan of the Robey lubricator. The revolving shaft A, which may be worked from any convenient part of the engine, but preferably from the cross shaft by an endless belt, is fitted with cranks B C, having depending wires D E. One depending wire, D, dips into the main oil reservoir F, and in rotating wipes off the oil carried by means of the fixed pin G into a smaller upper reservoir H, and the



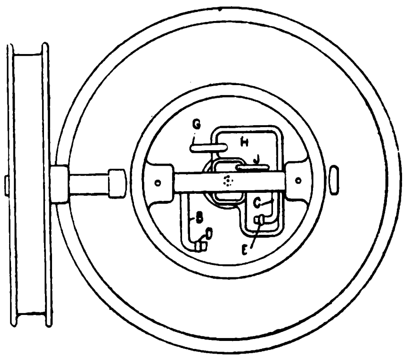


Fig. 157

Fig. 156

Figs. 156, 157.—cylinder lubricator (robey)

other wire, E, carries oil from this upper reservoir H to a fixed pin J and to the recess I, which leads it to the cylinder. The wire D lifting the oil from the main reservoir is proportioned so that excess of oil is always raised to the upper reservoir.

Fielding Lubricator

The lubricator shown at fig. 158 is on the principle of the bird-cage drinking fountain.

This lubricator consists of a closed air-tight chamber for

containing the oil supply, having a trough outside formed in the same casting, and at the base of this chamber a hole is drilled through the wall of the chamber, leading from its lower

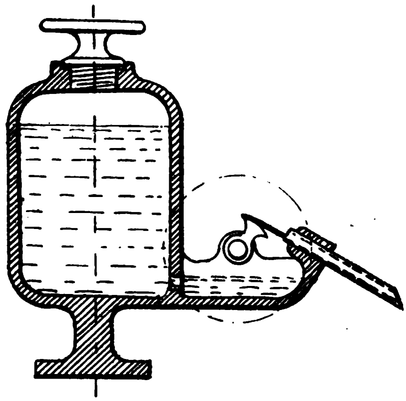


FIG. 158.—CYLINDER LUBRICATOR (FIELDING)

port into the tray; through this aperture the oil escapes, maintaining a constant level in the trough, and the oil is delivered from the tray by a wiper or wick. A removable plug is provided for filling the oil chamber.

CHAPTER XXI

CAMS

THE usual practice in designing the air and exhaust cams is to use cast iron. The gas cam, whilst also of cast iron, has a tool steel piece inserted to ensure a good edge for the gas roller.

Cast iron of good quality gives good results when the striking position of the cam to the roller on the lever is suitably arranged.

Figs. 159, 160, and 161 show various methods of constructing cams, and their respective openings of the valves.

Fig. 159, where a lifting lever of equal centres is used, the

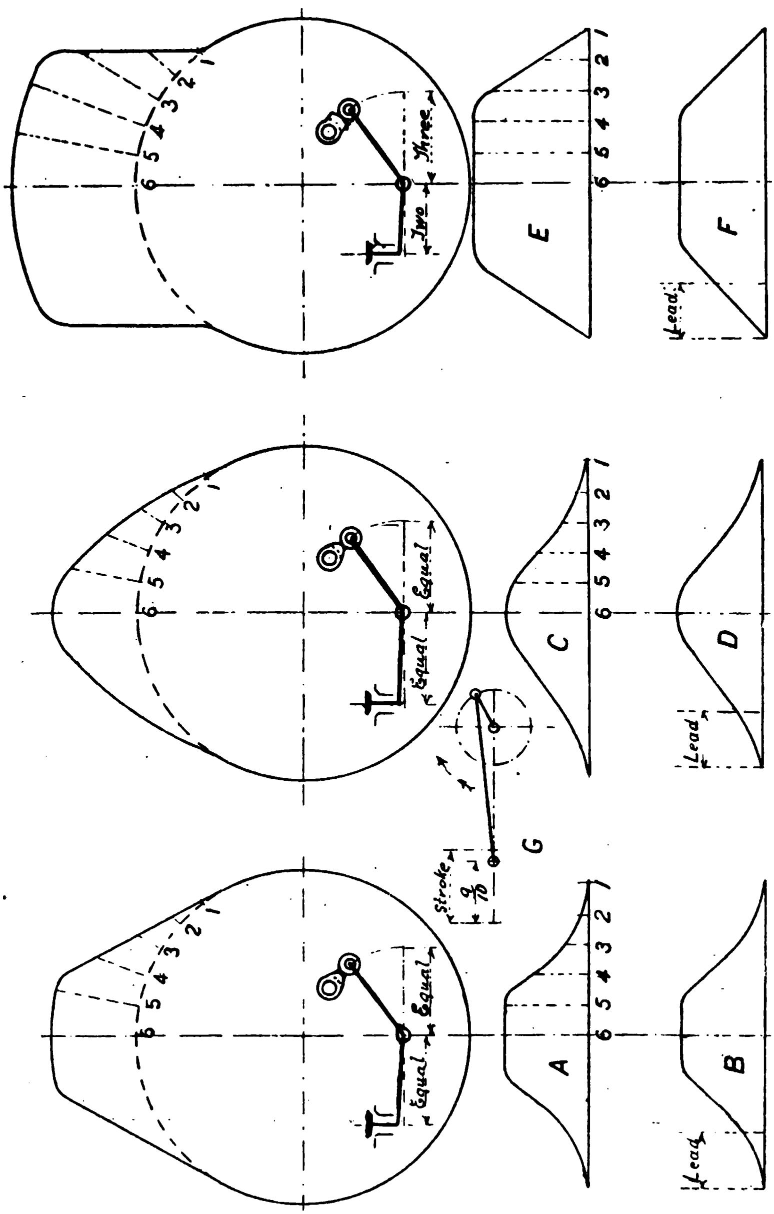


FIG. 159

FIG. 160

FIG. 161

FIGS. 159, 160, 161.—CAMS

lift of cam is shown at A, and the rate of valve opening and closing at B.

Fig. 160 shows the lift of lever of equal centres when using a parabolic cam. The lift of the cam is shown at C, and the rate of valve opening and closing at D.

In fig. 161 a quick opening and closing cam is shown, with a lever of unequal centres, the lift of the cam being shown at E, and the rate of valve opening and closing at F. The position of the crank at the commencement of exhausting stroke is shown at G.

CHAPTER XXII

EXHAUST SILENCING CHAMBERS

EXHAUST silencers are made in a variety of forms, all based upon the principle of allowing the exhaust products (at the high pressure of 30 to 40 lbs. per square inch) to expand into a much larger area than that of the exhaust pipe, thence to the atmosphere at a reduced pressure. The area of silencing chamber should be at least five times the volume of the cylinder.

Some makers use baffle plates, and though the advantage of a quiet exhaust is in many instances indispensable, great trouble is often experienced with the exhaust products through excessive baffling.

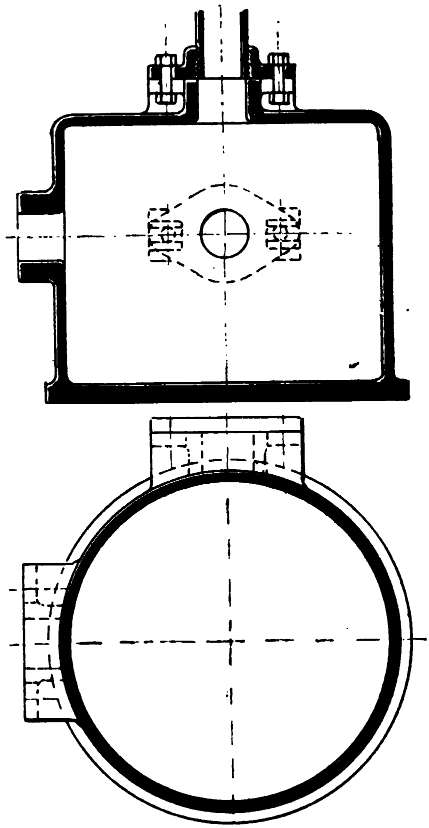
To expel the whole of the products of combustion would undoubtedly be a step in the right direction for high economy and hard continuous running.

This is somewhat difficult to accomplish without serious complications, yet the nearer this can be approached the better the results will be.

Fig. 162 is a sectional elevation, and fig. 163 a sectional plan of a very common design of exhaust silencing chamber. The exhaust gas from the engine may be arranged to enter at the side and out at the top, or to enter at the side and out again at right angles. In some cases two boxes are coupled together by a bridge piece pipe on top, the exhaust entering at the side

of the first box and out again to atmosphere from the side of the second box, or coupled at the side and the escape arranged from the top of the second box.

Fig. 164 is a sectional elevation of two 'Justice' silencers, and fig. 165 a sectional plan. This type of silencer is usually placed



FIGS. 162, 163. —EXHAUST SILENCER

at the end of the exhaust pipe and partially filled with shingle, and there are cases where shingle is used as a silencer when placed in a pit arranged to receive the end of exhaust pipe.

Fig. 166 is a section of divisional silencer, and fig. 167 a cross section. In this form the exhaust inlet may be arranged

at either end. The extent of silencing is determined by the number of baffle plates, which are held together by a bolt passing through centre, though not held hard between the two end covers. When using this form of silencer it is necessary

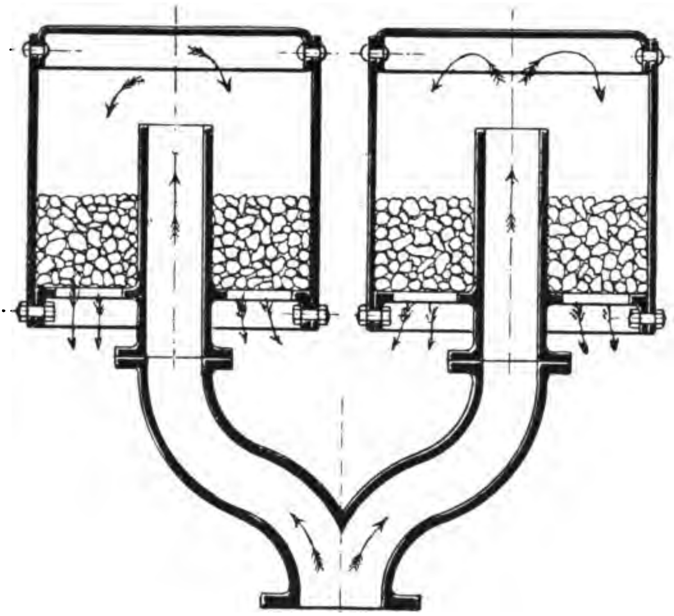


FIG. 164

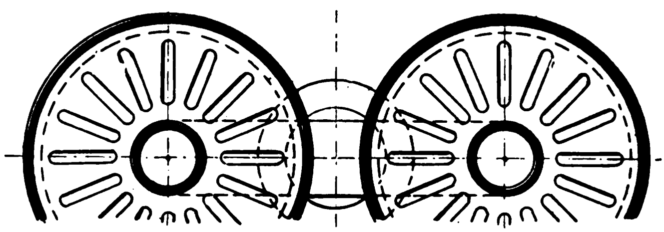


FIG. 165

FIGS. 164, 165.—EXHAUST SILENCER (JUSTICE)

to fix the box some feet from the engine to avoid 'back' pressure. It can be fixed in a horizontal or vertical position.

Fig. 168 is a section, and fig. 169 a cross section of another design of the same type, where the loose plates are held in

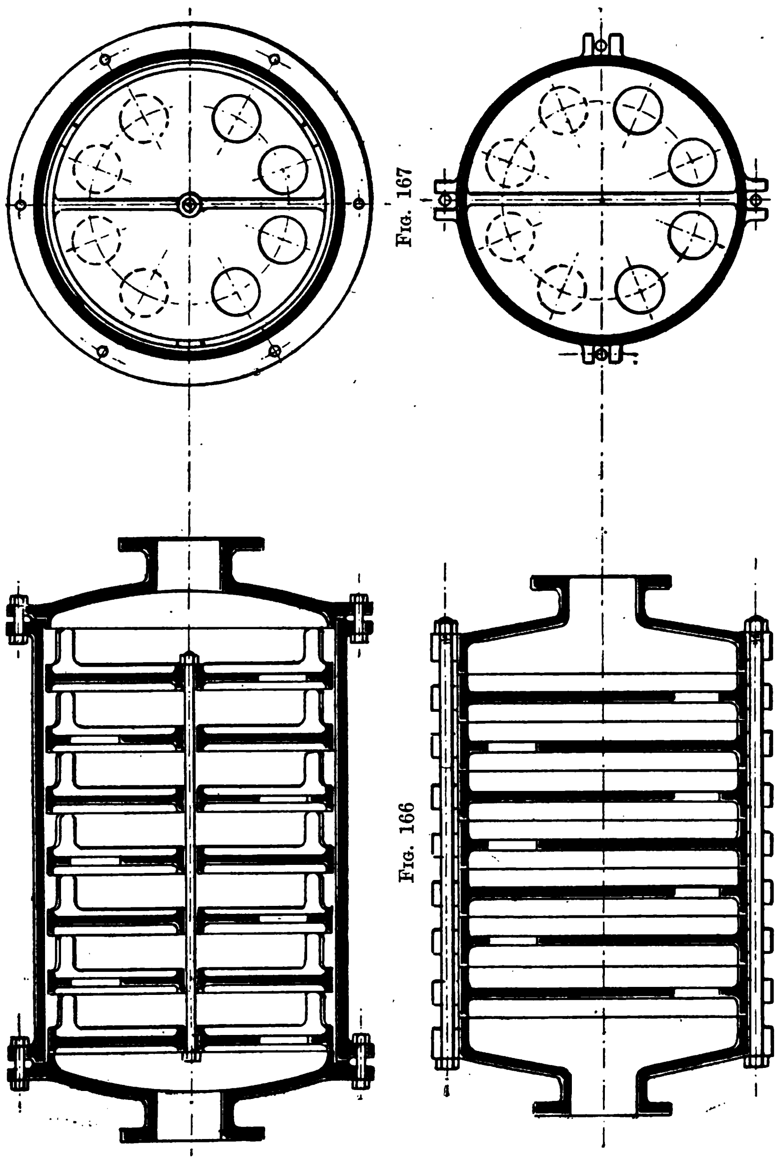


Fig. 167

Fig. 169

Fig. 166

Fig. 168

Figs. 166, 167, 168, 169.—Exhaust Silencers

position by bolts outside the main casting, instead of through the centre, the end covers pressing hard on the plates.

In every arrangement of exhaust silencer provision should be made for draining off the water which may collect through condensed gases or rain getting into the escape pipe. A convenient method is to arrange a moderate sized pocket in the form of a standpipe, arranged in the lowest position and fitted with a drain cock.

CHAPTER XXIII

GAS METERS

THE capacity of a meter is calculated by the number of lights, consuming 6 cubic feet per hour, it is designed to supply. Thus, a 5-light meter is capable of passing 30 cubic feet per hour, though meters are very often worked to a considerably higher capacity than that for which they are designed, and the dry form can be safely expected to give $1\frac{1}{2}$ times the duty stamped.

Meter Light	Duty, Cubic Feet per Hour	Diameter of Inlet and Outlet	Approximate B.H.P. of Engine
		in.	
5	30	$\frac{3}{4}$	1
10	60	1	$2\frac{1}{2}$
20	120	$1\frac{1}{4}$	8
30	180	$1\frac{3}{8}$	12
40	240	$1\frac{3}{8}$	15
50	300	$1\frac{1}{2}$	18
60	360	$1\frac{3}{4}$	20
80	480	$2\frac{1}{8}$	24
100	600	$2\frac{1}{8}$	36
150	900	3	45
200	1,200	$3\frac{1}{2}$	73

The size of service pipes depends upon the distance and size of the main gas supply. If, however, the pressure of the gas is above, or not less than, 1 inch water pressure, and the distance from the main not more than 30 yards, the above meter sizes will be found suitable. It is advisable rather to increase the size of pipes to the meter than decrease them, and gas pipes of less than $\frac{3}{4}$ inch bore should never be placed in the ground.

CHAPTER XXIV

GENERAL ARRANGEMENT OF ENGINE

FIG. 170 is an elevation and fig. 171 a plan of a 9 B.H.P. gas engine, giving a convenient arrangement of engine, tanks, &c.,

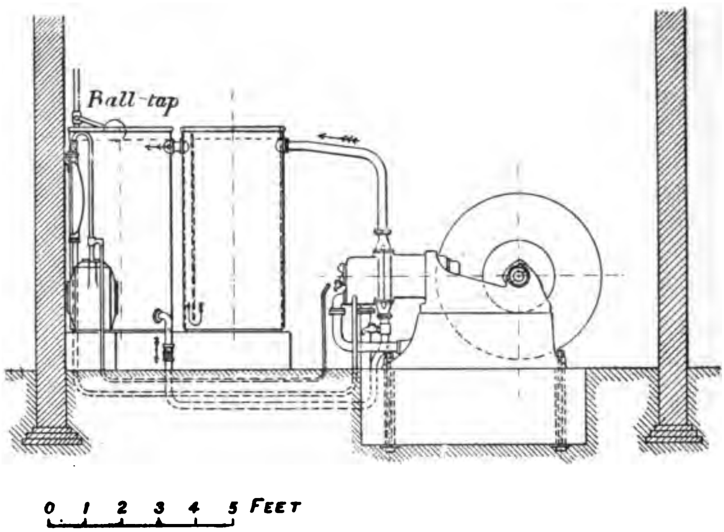


FIG. 170

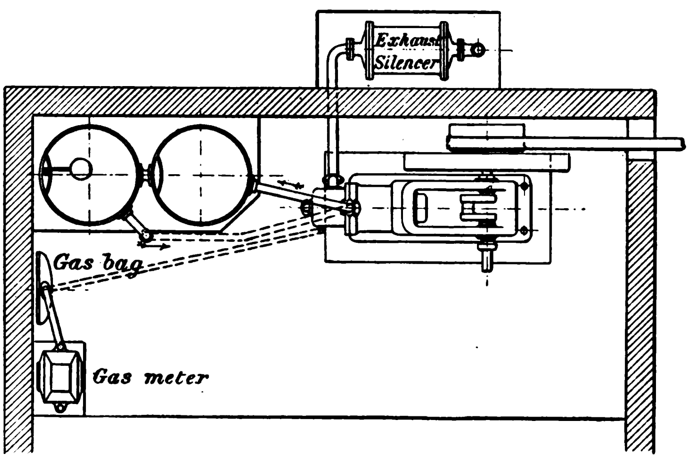


FIG. 171

FIGS.. 170, 171.—GENERAL ARRANGEMENT OF ENGINES

but the varying conditions of space and machinery to be driven make it impossible to fix any definite arrangement to suit all cases.

For the foundation, brick, stone, concrete, or wood is used; where convenient, concrete makes a good foundation, and admits of holding-down bolts having a firm hold.

It will be seen that two cooling tanks are used; the inlet and outlet of the water to the cylinder and combustion chamber are shown by the direction of the arrows. A number of vessels arranged so that the hot water from the cylinder and combustion chamber returns to the top of the first water vessel, falling to the bottom and rising up the partition and into the top of the second vessel, and falling again to the bottom and to the engine, makes a most efficient method of circulating. The capacity of these vessels equals 56 cubic feet. The way in which a gas engine is fixed has frequently a great influence upon its future running. If the air necessary for combustion flows into the cylinder through a long, continuous pipe, indifferent firing of the charges will probably follow, causing great loss in power and troublesome explosions. Large gas engines should be provided with an air regulator, which in most cases is fixed near the engine, although much better results are obtained by arranging regulator on the end of air pipe. In some cases much longer air pipes are used than when testing engine at the works. For this reason air pipes should always be larger beyond the air box.

Gas standing in ordinary gas pipes for any length of time becomes mixed with air by diffusion. If the mixture of gas and air is not allowed to flow out before attempting to start an engine, a difficulty will be experienced; and it will be found the best plan to always test the gas before attempting to start for the first time, or after it has been standing for a few days, and a cock should be fixed in the gas pipe near the gas cock, with a pipe leading to the under-side of the water inlet pipe, with a small cock attached, which will not only serve the purpose of testing the quality of the gas, but may be left burning in frosty weather to prevent the water in the circulating pipe from freezing. If, on lighting the gas at this cock, it burns with a blue

or Bunsen flame, it is diluted with air, and should be allowed to burn until the flame becomes the colour of an ordinary gas jet. It may so happen that, although the engine may run fairly well with a light load, yet with a full load the gas supply may be found insufficient; so that, the gas bag being emptied, the supply is drawn direct from the main, with explosions in the air and exhaust pipe following as a consequence because the gas and air are not mixed in the proper proportions in cylinder. In case the supply of gas is throttled—i.e. the main is not large enough to suit the pressure, an accumulation of water, or obstruction in the pipe; sometimes by negligence in making joints. On the other hand, it may be all right at night, when the pressure is higher, the explosions taking place only during the day. All lights connected to the same main will fluctuate considerably, so that the Bunsen flame for heating the tube may persist in lighting at the air holes. If the gas is insufficient, the simplest remedy is to increase the size of the main. The increase in size will, of course, depend on the size of the main gas supply, and the distance the engine is fixed from this supply. However, the lowest pressure should always be known before the engine is fixed. Engines placed at the top of a building are better off in this respect.

CHAPTER XXV

SCAVENGING METHOD

THE first successful engine using a positive scavenger was the six-stroke engine invented by Linford in 1881; but the first four-stroke Otto cycle engine with positive scavenger was that invented by Mr. J. H. Hamilton, B.Sc., and exhibited by Messrs. Wells Brothers at the Crystal Palace Electrical Exhibition in 1891 and 1892. This engine was a 14 H.P. NOM., and used 16·5 cubic feet of gas per I.H.P. per hour when developing 27 B.H.P. The compression of the charge before ignition was 65 lbs. per square inch, and although using a differential piston the work absorbed in forcing the air through is, owing

to free passages, very slight, a reduction of $\frac{3}{4}$ lb. to 1 lb. per square inch from the indicator card will well cover it.

Although the advantages gained by exhausting the products of combustion have been disputed and re-disputed over and over again, there is no doubt that to get rid of the products as quickly as possible after the working stroke is completed is the right thing to do. Not only is the average pressure of the indicator diagram maintained more uniformly, but a greater power is developed for the same size of cylinder, with a marked decrease in the temperature of the cooling jacket water, and thus making the engine more suitable for hard continuous work. Under certain conditions, such as using a long exhaust pipe without a silencing chamber, when the pipe has become heated a partial vacuum is created (even with the ordinary valve settings this is very noticeable when the air and exhaust valves have been arranged in close proximity to each other). Several methods of eliminating the exhaust gases without the use of separate pumps have been used, the most noticeable being the 'Crossley-Atkinson Scavenging Method,' patented in 1893, and described in the 'Engineer,' December 1894.

Fig. 172 shows various positions of the crank pin with the valve settings, and fig. 173 is a weak spring diagram.

Assuming the crank pin to be in the position A at the time the exhaust valve opens, towards the termination of a working stroke, the exhaust valve is kept open until position B is reached. The exhaust valve in an ordinary 'Otto' engine would be closed about the point C when the piston is at the end of its stroke.

Fig. 172 shows approximately the crank pin in its various positions. The relative periods are also shown developed.

In the ordinary 'Otto' engine valve settings the air and gas enter during a half-revolution, the exhaust valve opens before the end of the outward stroke, and closes at the end of the in-stroke; but referring to fig. 172 it will be seen that in the scavenging engine the air valve opens before the end of the in-stroke and closes at the end of the out-stroke, and the exhaust valve opens before the end of the stroke but does not close until the piston has passed the dead centre, the air and exhaust valves being thus open together for about a quarter of a

revolution. When the exhaust valve opens there is a pressure of 30 to 40 lbs. left in the cylinder; the burned products on passing the exhaust valve begin to compress the gases immediately in front against the inertia of the column beyond, and this compressed area passes rapidly up the pipe until the whole column is in motion. Fig. 173 is a weak spring diagram

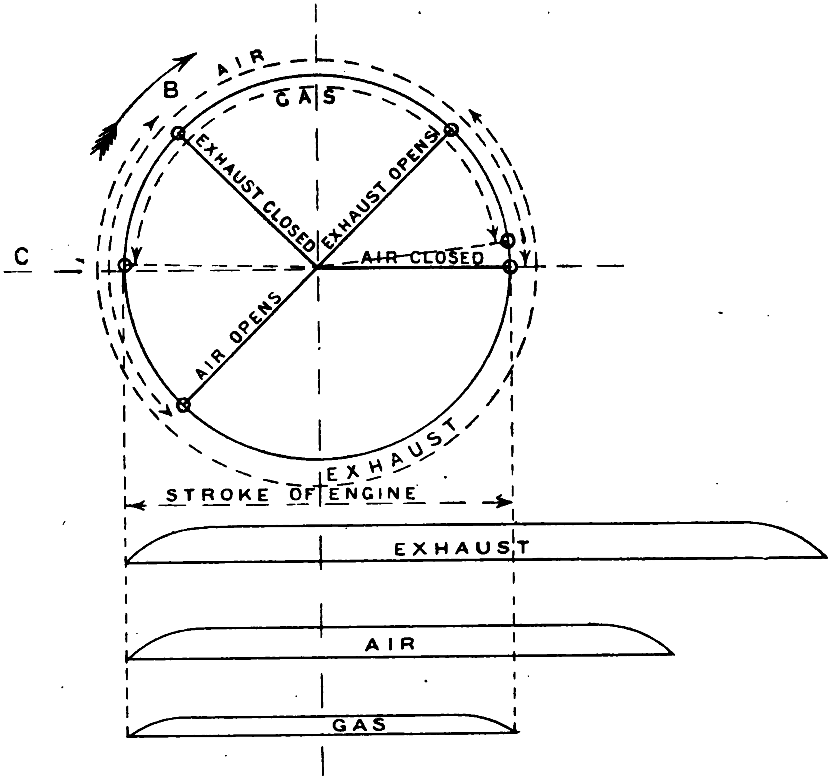


FIG. 172.—SCAVENGING METHOD

from one of Messrs. Crossley Brothers' engines, and it will be noticed that a period of wave-like oscillations is shown. The exhaust line rises above the atmospheric line; but had the exhaust not set the column of air in the exhaust pipe in motion, the back pressure would, of course, have been greater. As the piston nears the end of the in-stroke, the pressure falls below the atmospheric line, due to the momentum stored up in

the exhaust column, and the scavenging is effected during the time the air valve is open along with the exhaust.

It is, however, beyond dispute that very economical results have been obtained without 'scavenging,' and Mr. Lanchester

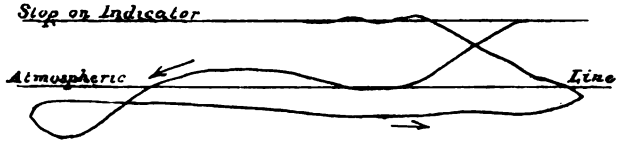


FIG. 173.—WEAK SPRING DIAGRAM (SCAVENGING METHOD)

has recently tested a 'Forward' engine having a cylinder 7½ × 14 inches stroke, running 195 revolutions per minute with a mean pressure of 84 lbs. per square inch, and the gas consumption per I.H.P. hour was only 17·25 cubic feet.

CHAPTER XXVI

LARGE POWER ENGINES

ALTHOUGH increase in compression before ignition has to a very large extent been the means of increasing the power and economy of gas engines, the author is inclined to think that this increase of compression has been overdone for large engines. In fact, without compensating advantages, increased expansion is essential, because there is less trouble with the exhaust.

With engines having large bore and short strokes, increased expansion is obtained with very high compression.

The difficulties are not merely in the construction of an engine which will withstand the heavy explosion pressures, but which will withstand them when aggravated by the differential stresses which result from the high temperature of combustion and the unequal cooling effect of the water in the jacket. There are also serious difficulties connected with the cooling of the piston, and with the ignition of the charge of poor gas in large cylinders. With such large dimensions and great forces the questions concerning the jacket, the exhaust valves, and piston become difficult, and great care has to be

taken to prevent overheating, and to secure as near as possible a regular mean temperature of the cylinder. The cooling surface is much less in proportion to the volume of the gases burned in the cylinder; the consequence is that the products of combustion retain heat to a far greater extent than in small engines, and the high temperature in the larger engines is liable to ignite the incoming charged, the result being that large engines at full power are more liable to back firing and pre-ignitions than those of smaller size.

The tendency is to construct engines of large power having a large bore of cylinder and short stroke—in some cases the stroke is little more than the bore of cylinder. These engines are run at not less than 800 feet piston speed per minute.

From a 'commercial' point of view it will be understood that the object is to construct an engine so that the cost of it per unit of power is low; but from a 'mechanical' and even 'scientific' point of view this is wrong, notwithstanding the fact that the theoretical efficiency increases with compression.

It must, however, be borne in mind that by constructing an engine with ordinary compression and increasing the expansion a large sized engine is required, and although, as already stated, in keen competition this class of engine may suffer, nevertheless the wear and tear is considerably reduced, and it is very questionable whether in large sizes there is any gain in the long run by adopting high speeds and short strokes combined with very high compression.

CHAPTER XXVII

FRICTION OF GAS ENGINES

It is generally accepted that a steam engine has practically the same amount of friction when driving all the moving parts and doing no other work as it has when doing its maximum duty. This applies equally to a gas engine, and since this is so, a gas engine of any dimensions will require a certain amount of power to keep it moving at its normal speed; all additional power is practically effective horse-power, consequently the

greater the power the engine can be made to give out in regular work, the higher its mechanical efficiency will be— i.e. $\frac{\text{B.H.P.}}{\text{I.H.P.}} = \text{M.E.}$

There is a difference between the friction of an engine with hot and cold water in the cylinder jacket, but this is seldom taken into account.

The most satisfactory data have been furnished by Professor Thurston. His experience proved that the friction of a steam engine was practically the same, no matter what power it was giving out.

A gas engine had to give a certain I.H.P. to drive itself, and this amount represented a constant amount, or dead load; all the power indicated in excess of this was effective or useful load put into the work actually done.

It must, however, be borne in mind that the temperature of the water jacket plays a very important part, the efficiency varying considerably with the temperature.

CHAPTER XXVIII

TESTING GAS ENGINES

THE first engine of each size made should be treated as follows at the works before delivery: Before heating the ignition tube, a cock should be fixed on the combustion chamber; turn fly-wheel round sharply, drawing in a few charges of gas and air, open this cock and apply a light, the object of which is to determine the quality of the mixture; if it burns with a characteristic blue flame it will be rightly proportioned, if it burns indifferently there will be too much air, whilst if it burns with a white cap there will be too much gas. In all cases the mixture should be regulated before attempting to start the engine.

Having made a start and got the engine fairly warm, a power card should be taken, which will show at a glance if the valve settings are correct.

Indicators are invariably fixed on the combustion chamber, and for this purpose a hole is tapped $\frac{3}{4}$-inch Whitworth, and fitted with a plug. It is not advisable to have any connection between the indicator cock and the combustion chamber, the hole in which should not be less than $\frac{1}{2}$ inch.

When the indicator cock is closed, the indicator pencil should remain at rest; if not, a leak past the plug will be the cause of the pencil moving up and down, and preventing an accurate atmospheric line being obtained. As already explained, great care must be exercised in coupling up the indicator cord.

For practical purposes the following is the usual method of indicating a gas engine: Having fixed the indicator, it is advisable before taking a diagram to run the engine, say, fifteen minutes, to allow time to get rid of the moisture in the cylinder. Diagrams may then be taken, and will at a glance show the valve settings and the difference between the force of explosion before and after the cut-off is obtained.

It will be observed that the indicator diagram is the result of two motions: the vertical motion of the pencil due to the pressure in the engine cylinder, and the horizontal motion of the paper which represents the travel of the motor piston. Hence any point on the curve indicates the pressure in the cylinder corresponding to that position of the piston given by the horizontal distance along the line.

When we introduce the idea of time and compare amount of work done by an agent in a given interval of time, we use the term 'power' or 'rate of doing work.'

To find the horse-power of any agent it is only necessary to calculate in foot-pounds the work done by it in one minute and divide by 33,000.

The indicated horse-power of an engine is the rate at which work is being done on the piston by the working substance as calculated from the indicator diagram, the speed of the engine—that is, the number of turns the crank shaft makes per minute—not being taken into account, but chiefly the number of explosions per minute and average effective pressure (after deducting the pressure during back and charging stroke) and

the mean of the first explosion after cut-off and, say, two others being taken.

Therefore, let P = mean effective pressure of diagram,

S = length of stroke of piston in feet, and

E = explosions per minute.

A = area of piston in square inches.

$$\frac{P \times A \times S \times E}{33{,}000} = \text{indicated H.P.}$$

Of the total indicated horse-power in an engine part is spent in overcoming the frictional resistance of the mechanism, and the remainder that is available for effective work is called the actual, brake, or effective horse-power.

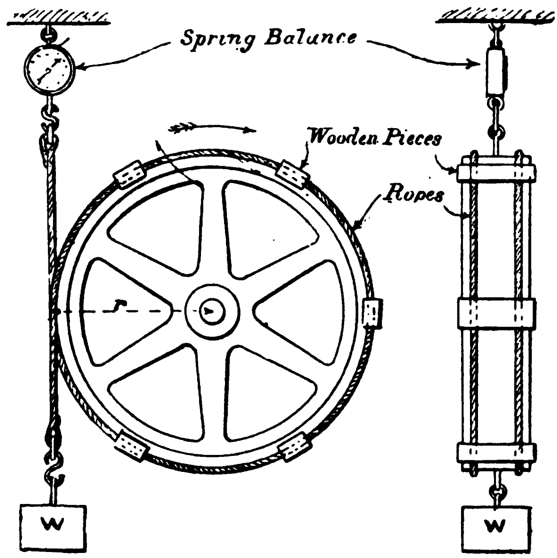


FIG. 174.—FRICTION BRAKE DYNAMOMETER

Undoubtedly the simplest and most accurate method of gauging this is by means of a brake as shown at fig. 174. It consists of an endless rope, in two turns kept apart from, as well as from slipping off the brake wheel by wooden cross-pieces. These should be laced to the ropes, and kept well clear of the rim of the wheel. It is not advisable to fasten the rope to the block by screws or nails, as these are liable to touch the

rim of the wheel and make it excessively heated by the friction so as to burn the rope. Grease, tallow, paraffin, and plumbago are often used to lubricate the rope and blocks. The more lubricant is used, the greater will be the variation on the spring balance.

It is possible and practical to run a wheel of 60 inches diameter with a load equal to 12 H.P. on the rope for ten hours with safety without lubricant; in fact the author has run an engine fitted with a 48-inch wheel, and having 30 lbs. on the rope, for 23½ hours without lubricant of any description. Providing the wheel is turned smooth on its face and a good close strand of rope is used, lubricants are unnecessary, and there is only slight variation on the spring balance.

Engines developing 14 to 30 B.H.P. should be tested with flywheels split at the boss. If not, there is a great danger of the wheel seizing on the shaft. Above 20 B.H.P. all wheels should be arranged with a water-trough rim.

To find the actual horse-power

Let W = gross load

w = average pull on the spring balance, which must be deducted from W to give the nett load.

r = radius of brake wheel and rope to point of suspension, the effective circumference $2\pi r$ feet.

N = revolutions of wheel per minute.

Therefore the work done against friction is

$$(W - w)\, 2\pi r N \text{ foot-pounds per minute.}$$

Hence we have

$$\text{Horse-power absorbed} = \frac{(W-w)\, 2\pi r N}{33{,}000}.$$

CHAPTER XXIX

INDICATORS FOR GAS ENGINES

THE principal use of the indicator is to give a graphic representation of the varying pressures in the cylinder of gas engines, enabling engineers to determine the amount of work done

by the working fluid, and to detect faults in design which might otherwise escape notice. But the correct interpretation of the diagram is by no means the simple matter it appears at first sight, as it involves most careful study and long experience. The spring and moving parts constitute, of course, the most important details of the instrument. Each indicator is supplied with a number of springs of different strength or stiffness to suit different pressures and speeds, the object always being to obtain the largest possible diagram which can be had under the conditions of speed and pressure. The different springs are arranged in terms of their compression in fractions of an inch, under a pressure on the piston of 1 lb. per square inch, or a direct load of ½ lb.; and the springs are numbered accordingly, the limits of pressure for which the spring is available being marked on its boss. The scales used are generally multiples of 4 or 8, so as to allow for conveniently using an ordinary inch scale divided into eighths for measuring up the diagrams. The divisions of the scales supplied with each spring are uniform throughout the range, on the assumption that the deflection of the spring is always for this range directly proportional to the load. This is not strictly true; and it would certainly be more accurate to divide each scale separately from the spring, instead of forcing the spring, as it were, into a certain predetermined scale. The error under the present system is, however, not large, amounting, according to the investigations of Professor Reynolds and Mr. Brightmore, to a maximum of about 1 per cent. in ordinary good springs, and this is quite insignificant compared with other errors to which the diagram is subject. For ordinary purposes this slight disadvantage is more than counterbalanced by the great convenience of having a fixed scale.

The most recent improvements in the indicator have been in the direction of stiffening the spring and reducing the inertia of the parallel motion, so as to obviate as far as possible the oscillations of the pencil, and render the instrument applicable at the higher speeds which are daily finding more extended application.

Before using any indicator a motion card should be taken.

To do this all that is necessary is to take out the piston and spring, draw the atmospheric line, and allow the drum to return to its original position; then lift pencil. The line drawn should be a horizontal straight line.

When using an indicator for taking diagrams from a gas engine very great difficulty is experienced, owing to the sudden rise of pressure, and abnormally high cards are often obtained, in some cases reaching 400 to 600 lbs. above atmosphere. The strain is invariably severe: the temperature may affect the spring, and there is considerable risk of the piston sticking; therefore it is not desirable to place too much reliance upon the indicated horse-power of a gas engine.

Diagrams taken when the engine is cold are very different from those when the engine is hot. Then, again, the first diagram after a cut-off—after the cylinder and combustion chamber have been cleared of the products of combustion—is invariably larger than the succeeding ones.

Thompson's Indicator

Fig. 175 is a part sectional elevation of a small Thompson indicator, as made by Messrs. Schäffer & Budenberg, the chief distinguishing feature of which is the novel arrangement of light levers carrying the pencil.

The parallel motion is carefully designed to ensure that the pencil point describes a straight line, and the motion of the pencil point should be precisely proportional to that of the indicator piston throughout the stroke.

The link connecting the pencil arm to the piston rod has a ball-and-socket joint at the loose end to allow free motion.

A movable collar around the upper part of the cylinder swings round against a stop to prevent undue pressure of the pencil on the paper. This collar carries a fixed standard with radius bar, as well as a link with the fulcrum of the pencil arm at its upper end.

The parts which move with a high velocity are made as light as possible, consistent with strength and stiffness, in order to reduce their inertia to a minimum.

The paper drum is shown separately in section, fig. 175.

By removing the outer cylinder, loosening the nut on the top of the drum spindle, and by turning the disc holding the flat spring inside, the latter may be readily adjusted to suit any speed of engine up to 400 revolutions per minute.

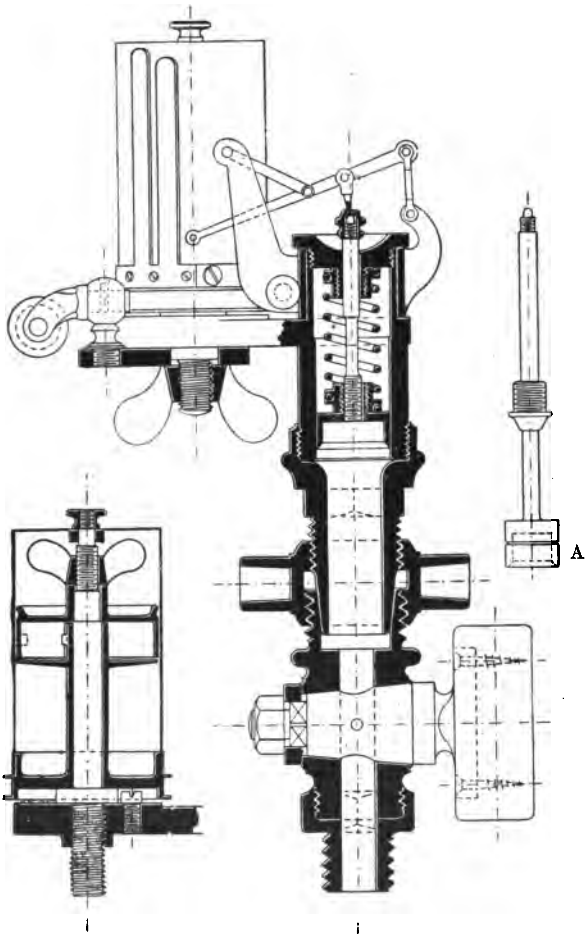


FIG. 175. —THOMPSON INDICATOR

When using this indicator for taking diagrams with exceptionally high maximum pressures a special piston A, one-half the area of the ordinary piston, is used, thus reducing the stress on the levers and motion bar and effectually overcoming the wave oscillation.

The Crosby Indicator

Fig. 176 is a sectional elevation of the Crosby indicator. It has a very light piston, parallel motion, and drum. The spring is made of one piece of steel wire, wound from the middle in a double spiral, its ends being screwed into the wings of the spring head D fixed to the cylinder cap A.

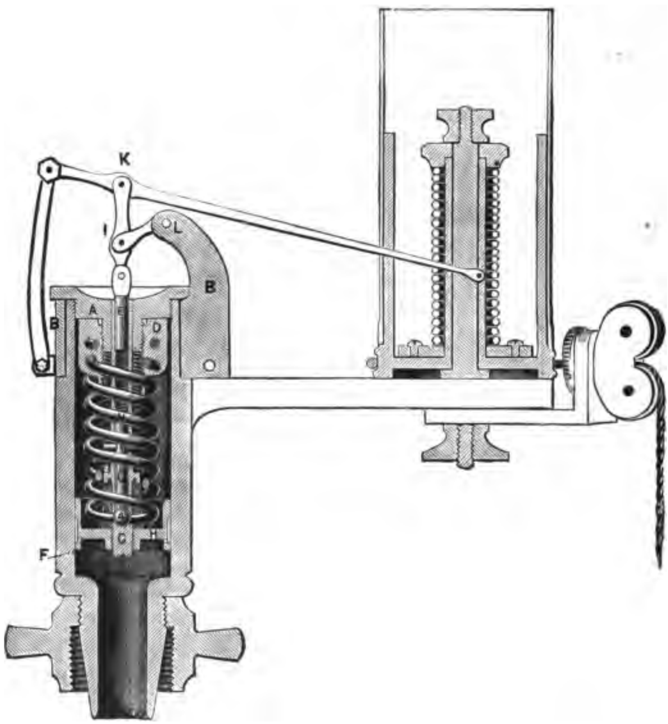


FIG. 176.—CROSBY INDICATOR

The final adjustment of the springs is made by simply screwing in or out of the head D. On the middle of the spring is brazed a small steel ball, which fits a socket in the hole on the piston rod, and is adjusted to the proper lightness by the screw G, so as to allow free motion and prevent sticking or twisting, the thrust on the spring producing a perfectly axial compression.

The steam or gas from the engine passes into the cylinder F and H around the piston, and keeps it from being forced sideways against the cylinder. It is desirable not to have the diagram more than 1·75 ins. high; hence, when measuring high pressures, use stiff piston-springs, which will at the same time lessen vibrations.

The very slight movement of the indicator-spring is then magnified to six times the range by the pencil.

The long pencil arm, necessary for this multiplication, is the weak part of this indicator when used for gas-engine purposes.

In careless hands the friction of the pencil on the paper sometimes amounts to tearing of the paper, or bending of the pencil when it is pressed too hard against the paper. This is prevented in the Crosby by a stop for the sleeve on the cylinder carrying the pencil movement. A screw comes against the stop, and can be adjusted to a nicety, so that the pencil point is allowed just to touch the paper and make a visible mark.

The paper drum has a short spiral spring, which can be tightened and adjusted by the collar and lock-nut at the top to suit the speed of the engine to be indicated. This spring offers increasing resistance, as it is compressed by the rotation of the drum, overcomes the inertia and friction of the drum, and thus maintains a constant stress on the cord connected by the reducing-gear to the engine-piston. With strengthened pencil-arm, and when used in a careful manner by practical and intelligent engineers, the Crosby instrument gives good and reliable cards. The Crosby Co. are now making a special gas-engine indicator for use on engines with a high initial pressure. The pencil motions of this instrument will be stronger than the ordinary steam-engine pattern, and the piston is only one-half the diameter.

The Tabor Indicator

Fig. 177 is an external elevation and fig. 178 a sectional elevation of the Tabor Indicator.

Referring to figs. 177 and 178, it will be seen that the most noticeable peculiarity of this instrument is the means employed

to communicate a straight light movement to the pencil. A plate containing a curved slot is fixed in an upright position and secured to a swivel plate on the cover of the steam cylinder. This slot serves as a guide, and controls the motion of the pencil bar. A pin which carries a roller is fixed on one side of the pencil bar, and this roller is fitted so as to roll freely from end to end of the slot. The position of the slot is so adjusted,

FIG. 177.—TABOR INDICATOR

and the pin attached at such a point on the pencil bar, that the curve of the slot compensates the tendency of the bar to move in a circular arc, and the end of the bar, which carries the pencil, moves up and down in a straight line when the roller is moved from one end of the slot to the other. It will be apparent that there is little chance for friction in this movement, and also the lightness of the bar and connections insures that

inertia will not exert a disturbing influence on the movement of the pencil.

Of the general features of this indicator it will be noted

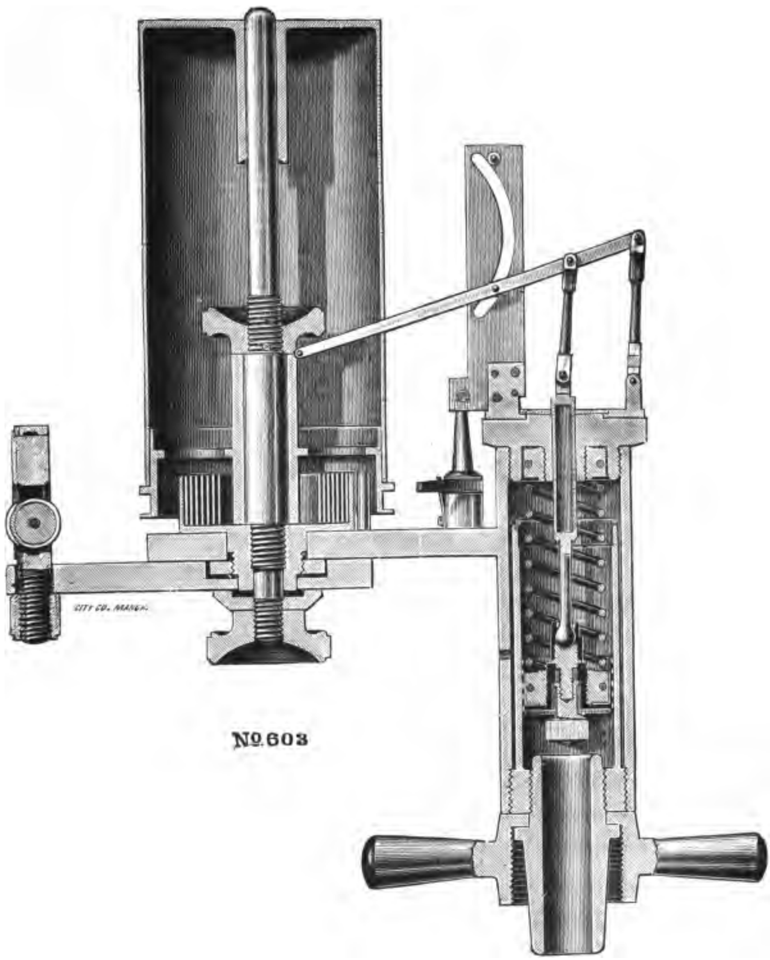


FIG. 178.—SECTION OF THE TABOR INDICATOR

that the base of the paper drum and the cylinder jacket are made in one piece.

The cylinder is a straight tube inside of the jacket, with an air space around the sides, and is attached to the jacket

by means of a thread cut on the bottom of the cylinder, the cylinder being thus left free to expand or contract without affecting other parts of the instrument.

The pencil mechanism is carried by a swivel plate fitted to the cylinder cover, and on which it can be freely turned to bring the pencil into contact with the paper drum. An adjusting screw passes through a projection on the swivel plate, and serves to turn the pencil mechanism to and from the paper drum, and also to regulate the pressure of the pencil on the paper.

A safety stop is provided inside the indicator to prevent undue compression of the spring and preserve the pencil movement from injury. This stop will be brought into play by the excessive pressures which sometimes occur when indicating gas-engines, or through the mistake of putting in too light a spring for the working pressures.

The springs used are of the duplex type, being made of two coils of wire fastened exactly opposite each other on the fittings.

A ratchet is cut—see fig. 176—on the edge of the drum carriage, and a pawl is so arranged as to engage in it whenever it is desired to stop the motion of the drum without unhooking the driving cord. This is exceedingly useful, saving time.

This instrument is somewhat larger than usual; some of the leading dimensions are as follows:

Diameter of piston . . .	0·7978	inches.
Diameter of paper drum . .	2·063	„
Stroke of paper drum . . .	5·5	„
Height of paper drum . . .	4·	„
Number of times pencil mechanism multiplies piston motion . .	5·	„
Range of motion of pencil point .	3·25	„

When taking pumping or power diagrams the Tabor Indicator gives admirable results.

The 'Wayne' Indicator

Another indicator which has lately come into prominence is the 'Wayne,' manufactured by Messrs. Elliott Bros.

Fig. 179 is an external elevation. and shows indicator arranged for taking line diagrams.

The distinguishing features are, rotary movement of parts connected to tracing point, no parallel motion, and the spring arranged outside of the cylinder. The piston, which is made of steel, consists of two tongues, or leaves, standing out from

FIG. 179.—THE 'WAYNE' INDICATOR

opposite sides of the piston rod, the rod passing through both ends of the cylinder; the leaves forming the piston reciprocate in a rotary manner between abutments from opposite sides of the inner periphery of the cylinder. These abutments fit the piston rod between the leaves of the piston; the steam or gas, after passing the stop-cock (which is connected to the indicator

by ball fittings, thus allowing the indicator to be set at any angle) is divided, and each half enters the cylinder near the abutments on opposite sides or diameters, thus acting upon both leaves of the piston with equal pressure; and the piston and piston rod, carrying the tracing point fixed on one end, are turned in a rotary direction.

The spring is double coiled from one piece of wire; the cross piece of wire joining the two coils is held in a V slot in the end of the piston rod by a spiral grooved cap; the other ends of the spring are fixed to a small plate having two perforations, which fit on two steel pins standing out from one end of the cylinder. The tracer is fitted with a brass point for metallic paper, lead point for plain paper, or a hard steel point for marking on special black faced paper.

The paper is held in a cylindrical form, concentric with the piston rod, in light spring clips at each end of a sliding bar; from one end of the bar a cord is taken once round a pulley to which it is fixed. From the other end of the sliding bar a cord is taken round the other side of the pulley; then, passing between guide pulleys, it is attached to the engine in the usual way.

An arrangement is shown on fig. 178 for taking the diagram in parts or lines, with a mechanically limited stroke for increase of pressure at the steam end of the line, and a corresponding down stroke on the expansion part of the line, so that only a strip of each diagram is taken at a time. This limiting is arranged by a segment of a worm wheel mounted concentric with the piston rod. This cannot give accurate results unless all the consecutive diagrams are identical.

The drum and sliding bar are aluminium, and are very light. The weak point of this indicator is the sliding bar; as already stated this bar is made very light. Lightness is essential, but greater bearing surface should be provided, or some method of taking up the wear. The diagrams taken with this instrument are very reliable.

CHAPTER XXX

DIAGRAM AVERAGING INSTRUMENT

THIS instrument was originally designed to measure the average pressure of an indicator diagram, but it can also be applied, if desired, to measure the areas of other irregular figures.

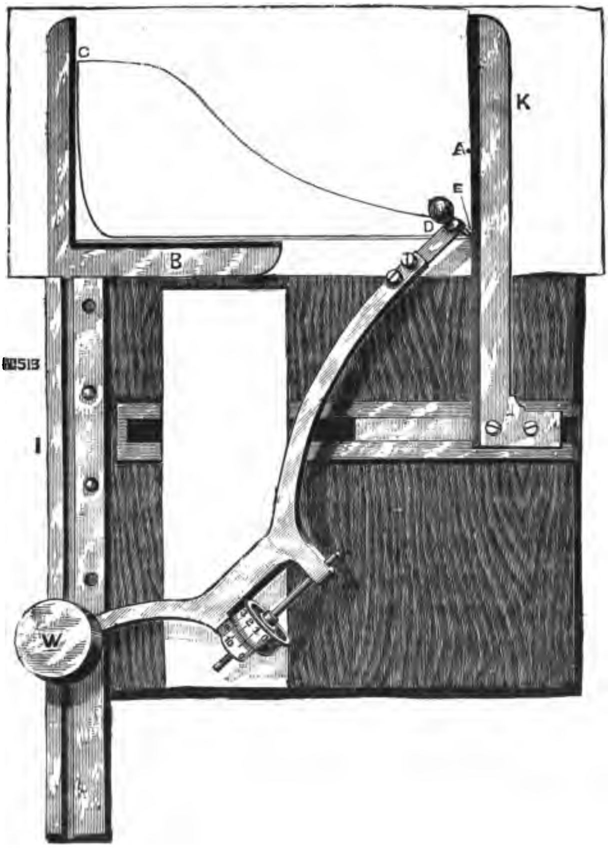


FIG. 180.—DIAGRAM AVERAGING INSTRUMENT

Referring to fig. 180, it will be seen that the averager consists of an arm, having a tracing point at one end and a hardened steel pin at the other, and carrying a graduated wheel

on one side, the axis of the wheel being parallel to a line drawn from the hardened pin to the tracing point. This arm is used on a board having a metal square, C, B, fixed at the left-hand side, with a grooved plate, 1, below it, for the hardened pin to slide in. On the right-hand side of the board is a straight-edge, K, fastened to a slide, which may be moved towards or from the grooved plate, in order to accommodate different lengths of diagrams. Alongside of the grooved plate, a strip of specially prepared paper is fixed for the graduated wheel to run in.

In using the diagram averager, an indicator diagram is first placed under the clamps C and K in such a position that the atmospheric line is parallel with the lower edge B of the square C B, while the extreme left-hand end of the diagram nearly touches the perpendicular edge, C. The sliding clamp K is then moved to the left until its inner edge almost touches the right end of the diagram. Fig. 180 shows the correct position of the diagram and clamps, *i.e.*, the diagram must be so placed that the centre of the tracer D, when touching the clamps, will come directly over the centre line.

The arm of the instrument is next placed on the board, with the pin at the lower end, resting in the groove, I, and the weight W applied to the top of the pin, to keep it in the groove. A slight indentation is then made in the paper at E, with the tracer D, when it is touching the clamp K, and preferably on the line of the diagram. This serves as a starting-point. The graduated wheel is then turned so that its zero is opposite the zero on the vernier, taking care that the tracer D does not move till the wheel is set.

Next move the tracer D carefully over the line of the diagram, moving to the left along the exhaust line, and to the right along the admission and expansion lines, until the starting-point E is reached (the wheel then shows the area of the diagram, but no account need be taken of this in ascertaining the average pressure), then move the tracer upwards, keeping it against the edge of the clamp K until the wheel returns to zero, and make another indentation in the paper. This is indicated at A. The distance between the two indentations equals the average height of card, and if measured by the scale corresponding to

the diagram will show the average pressure, either in pounds per square inch or in kilogrammes per square centimetre, according to the spring and scale employed.

The theory of this instrument is very simple.

Referring to fig. 181 the lines A, A_1, A_2, A_3, and A_4, roughly represent an indicator diagram, and the line A_1, B_1 represents

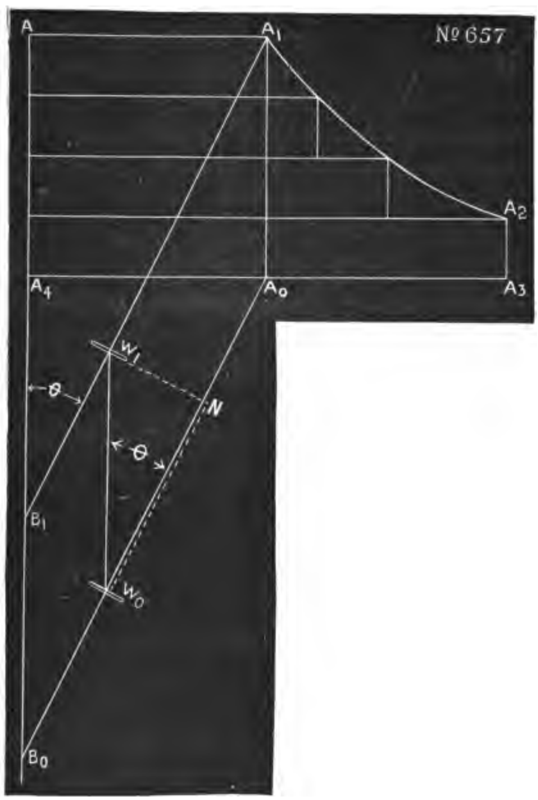


FIG. 181.—DIAGRAM AVERAGER

the arm of the instrument in its initial position, A_1 representing the tracing point. Assume that this arm is moved downwards to the position A_0, B_0, then the area moved over the line is the space A_1, B_1, B_0, A_0, which is exactly equal to the rectangle A, A_1, A_0 A_4, as it is on the same base and between the same parallels.

Let L equal the length of the line A_1, B_1, θ equal the angle between this line and the vertical traversed, then the area moved over by the line A_1, B_1 is equal to L 8 in. $\theta \times H$. The axis of the measuring wheel, W, being parallel to the line A_1, B_1, this wheel will rotate in precisely the same manner as if its axis coincided with that line, and it will be so represented in this explanation.

When the arm is moved to A_0 B_0, the wheel W is moved to W_0. Resolving this movement into its components, there is first, H cos. θ (represented by N W_0), and this component being parallel to the axis of the wheel, cannot cause rotation. The second being H sin. θ (represented by W^1 N), which is in the direction of rotation of the wheel, will cause the wheel to turn round on the paper over which it runs, through a length of its circumference equal to this; but, as shown before, the area moved over by the arm was L sin. $\theta \times H$, and therefore this area is also equal to L $\times$ the rotation of the wheel.

Next move the tracing point A_0 to A_4—during this movement the wheel will revolve through a certain angle which need not be considered (as will be seen later); then move the tracing point from A_4 up to A; the motion now is parallel to the axis of the wheel, and the wheel will not revolve. Finally, move the tracing point from A to A_1, its original position. During this movement the wheel will revolve through the same angle that it did in moving from A_0 to A_4, but in the opposite direction, which motions cancel each other. Therefore the final rotation of the wheel at A is proportional to H sin. θ; and, as already shown, the area A A_1 A_0 A_4 is equal to L sin. $\theta \times H$; therefore the rotation of the wheel is proportional to the area enclosed by the line which the tracing point moves over. It will be readily seen from the above that only vertical components of its movement leave any permanent record on the wheel, the horizontal components cancelling each other when the tracing point is brought back to its starting-point.

Next take the whole of the diagram, including the curved side A_1 A_2. Approximately this diagram is equal in area to the sum of the rectangles shown, and will be exactly equal to this if the rectangles are narrow enough. Now from the explana-

tion above it will be readily seen that the area of each of these rectangles could be obtained separately and, as the movement along the line A A_4 does not affect the wheel, if the starting-point was at A and each rectangle moved over in turn without removing the tracing point from the paper, the wheel would mechanically add the areas of these rectangles together, and the result would be the area when the tracer was returned to the starting-point A. It will also be readily seen that as in the horizontal movements of the pointer over the lines of the rectangle cancel each other, the result will be the same if the tracing point is simply moved over the boundary lines of the diagram.

If this explanation has been carefully followed, it will readily be seen why the instrument gives the average height of a diagram when the tracer is moved upwards against the movable clamp after completing the circuit; for as the tracer is moved upwards until the wheel returns to zero, the arm will pass over a parallelogram the area of which is equal to the area shown on the wheel, or the area of the diagram measured. And as shown, this parallelogram is on the same base and between the same parallels as the rectangles found by drawing horizontal lines from clamp to clamp through the two indentations made by the pointer; therefore this rectangle is equal in area to the diagram, and as it is of the same length, its height must be the average height of the diagram.

By means of the averager a skilful operator can measure fifty diagrams per hour.

CHAPTER XXXI

SPEED COUNTERS

Although the speed of an engine may be taken by counting the revolutions made in a known time, this method is only of use for approximate work; therefore it is necessary to use a counter which can be worked from the crank or side shaft of an engine, and which will record the exact number of revolutions made in any given time. A very simple form of such a counter is shown at fig. 182, which is available for reciprocating and rotary motion in both directions.

The lever H is connected for counting reciprocating movements; the angular throw of this lever must not be less than 60°. For counting revolutions the lever H must be removed, and the rod or spindle Z is inserted into the opening at the back of the instrument. The counter will then register revolutions of the spindle Z.

The counting mechanisms consists essentially of a short oscillatory lever which is actuated by means of the lever H or rod Z and is provided with two projections engaging alternately with the teeth of a ratchet wheel, so as to turn the wheel through one tenth of a revolution in the same direction for each revolution of the spindle Z or stroke of the lever H. The spindle of the

Fig. 182

ratchet wheel carries a disc provided with a pin and corresponding recess, which serve to propel the next wheel through one-tenth of a revolution for each revolution of this wheel; and, similarly, each succeeding wheel turns the next following one-tenth of a revolution after having completed a whole revolution. Each wheel has a dial with ten figures, of which only one is visible at a time; consequently the figure next to the lever indicates units, the second tens, the third hundreds, and so on. When all dials show 9 the next stroke or revolution changes them all to zero, and the counter starts afresh.

The counting is perfectly reliable, even at very high speeds, because each wheel is locked in position by the edge of the next disc engaging the space between the two succeeding teeth.

The illustration shows this counter provided with an arrangement for re-setting all figures to zero. For this purpose each wheel is mounted on a carrier or short lever, which swivels on a pivot screwed into the base of the counter. After removing the cover of the counter and releasing the catch, the wheels can be all disengaged and set to zero.

HARDING COUNTER

Fig. 183 is an external elevation and fig. 184 shows the counting mechanism.

The figures are engraved upon a number of wheels, mounted on a separate shaft. When each wheel has completed a revolution two small projections engage with the corresponding small toothed wheels, causing the latter to turn the next wheel

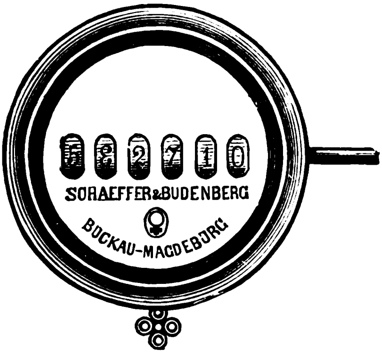


FIG. 183

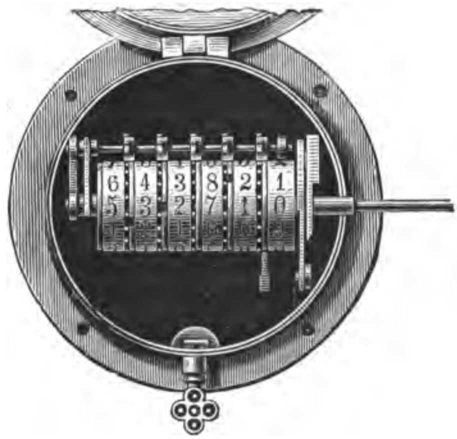


FIG. 184

through one-tenth of a revolution. The small wheels also serve to lock the large wheel in position after each movement.

The end of the secondary shaft carries a lever, the end of which rests loosely on the main shaft, thereby holding the large wheels in engagement. Upon raising this lever the wheels may be disengaged and set to zero.

The actuating mechanism resembles in principle that employed in the counter shown at fig. 182, and this counter is also available for reciprocating and rotary motions in both directions.

TACHOMETER, OR SPEED INDICATOR

Fig. 185 is an external elevation of a simple form of tachometer, an instrument which serves for indicating in a continuous manner the speed of rotating shafts in revolutions per minute, and is well adapted for checking the speed of engines when they are required to work with great regularity of speed.

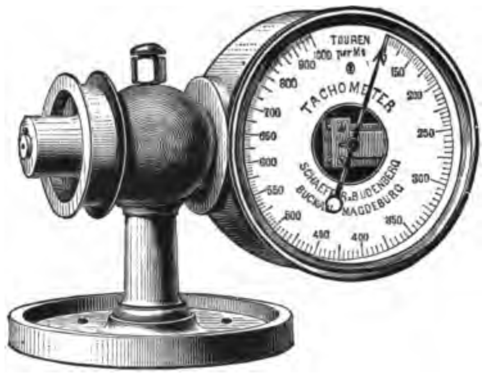


FIG. 185.—TACHOMETER, OR SPEED INDICATOR

The apparatus can be fixed in any required position for slackening the nut shown in the illustration ; it can be turned round completely in the support.

The pulley may be driven in either direction, when the actual speed of driving shaft is calculated from the ratio of the diameter of the driving pulley to that on the indicator.

This instrument is often fixed or coupled to a shaft, so as to constantly record the speed of it.

TACHOMETER

This type of tachometer shown in figs. 186 and 187, which is intended for use by hand, constitutes a modification of the larger instrument shown at figs. 183 and 184.

It is very light and portable, and will indicate the speeds of rotating shafts with the same degree of accuracy as the larger instruments.

This tachometer is employed by holding it with a slight pressure of the hand against the end of the rotating shaft so that the steel bit provided on the end of the apparatus enters the centre mark of the shaft. The instrument will then indicate directly and continuously the precise speed of rotation of the shaft.

This instrument is also provided with two sets of toothed wheels for increasing or reducing the relative speed of the tachometer in the proportion 1 : 2.

FIG. 186

FIG. 187

CHAPTER XXXII

CALORIMETRY

HITHERTO the heating or calorific value of combustible gases has generally been identified with their candle power; a correct determination of the former could, however, only be obtained by a difficult analysis, which an expert analyst would require several hours to complete.

We therefore find the economy of gas engines is expressed in so many cubic feet of '16 candle power gas per I.H.P. or B.H.P.' In using this standard the fact is altogether overlooked

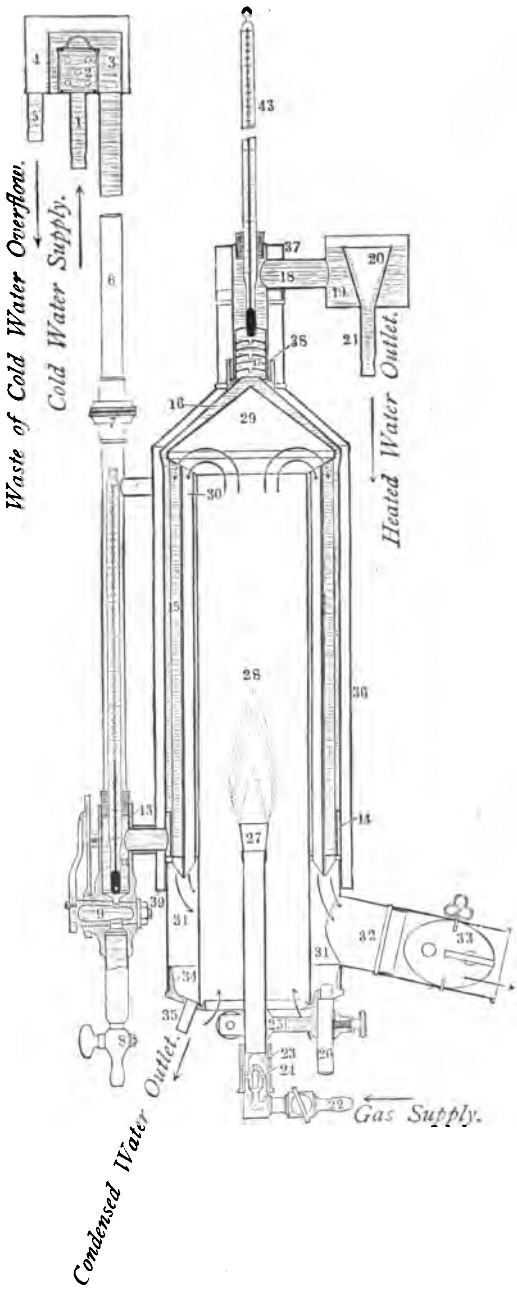


FIG. 188.—JUNKERS' CALORIMETER

that not only may the heating value of gases from different companies vary very much, although their photometric value may be practically the same, but also that gas taken from the same main, at intervals of only a few hours, is liable to vary as much as 20 per cent. Besides, if one quality of gas shows a higher candle power than another, it does not by any means follow that its heating value has increased in the same proportion.

Modern practice gives ample means of producing a gas of brilliant candle power, while its heating value may be very poor.

Considering the great extension which the use of gas has experienced as an agent in heating and in producing motive power, an apparatus has become absolutely indispensable which will enable any person of average intelligence to ascertain the heating value of any specimen of gas that may be used for such purposes.

From practical experience the author is satisfied that Junker's Calorimeter fulfils these conditions.

The principle on which this apparatus acts is, that the heat generated by a flame is transmitted to a current of water, flowing at a constant rate, and measurements are taken :

1. Of the quantity of gas burned ;
2. Of the quantity of water passed through the apparatus ;
3. Of the difference in the temperatures of the water on entering and on leaving the apparatus.

Fig. 188 is a sectional elevation, fig. 189 sectional plan, and fig. 190 general arrangement of Junker's Calorimeter, with gas meter, gas governor, pressure gauge and thermometers. A flame, 28, is introduced into a combustion chamber, formed by an annular copper vessel, the annular space being traversed by a great number of copper tubes, 30, connecting the roof with the bottom chamber. The heated gases circulate inside the tubes from the top to the bottom, whilst a current of water ascends outside the tubes in

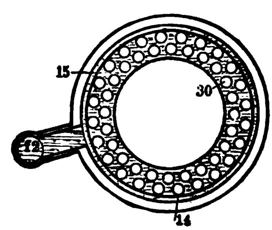


FIG. 189

the opposite direction. By means of this most suitable arrangement of counter currents, all the heat produced by the flame is transferred to the water, and the spent gases escape through the throttle at atmospheric temperature. The pressure of the water current is kept constant by two overflows, 3 and 20, and

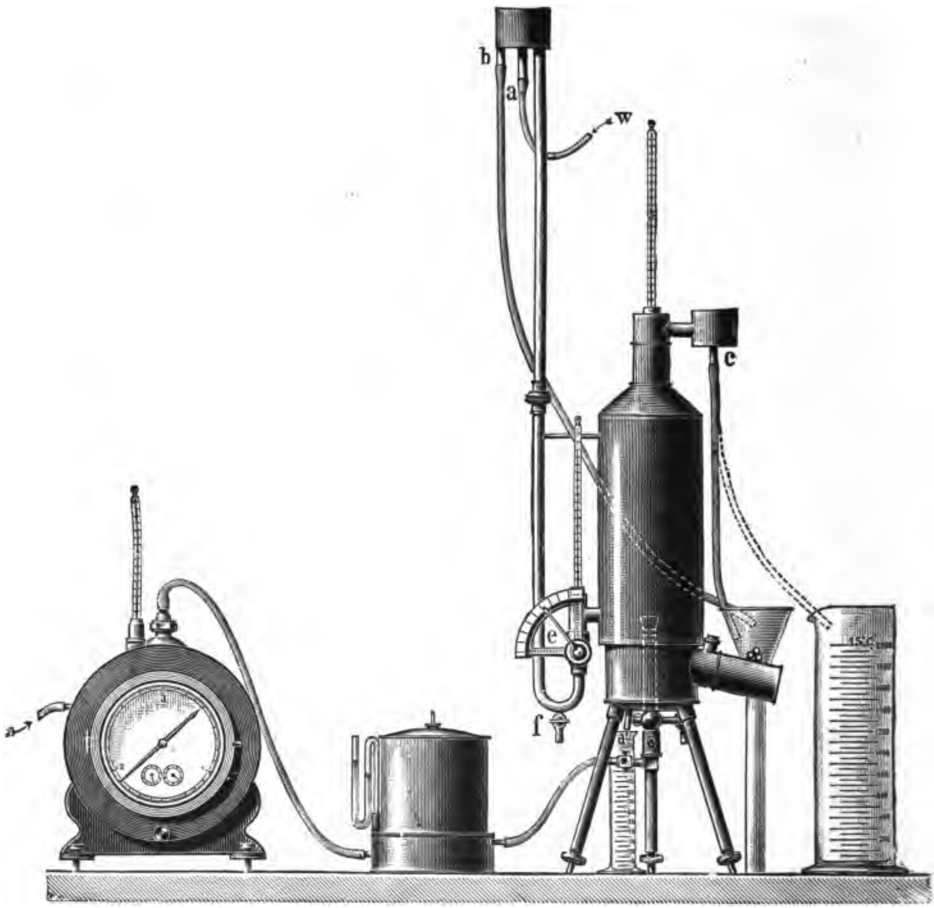


FIG. 190

the quantity of water passing through the apparatus can be regulated by the stopcock 9. A baffle plate, 14, surrounds the lower end of the tubes to ensure an even distribution of the

water, and in the neck of the apparatus, at 38, several discs with cross slots are arranged to ensure an intimate mixture of the heated water before it reaches the thermometers. Provision is made to collect the water which is formed during the combustion of hydrogen in the gases in the annular space, 34, and to pass it into a measure glass through the tube 35. To prevent radiation, the whole body of the apparatus is enclosed in an air jacket.

As the standard unit of heat generally used is the calorie, *i.e.*, the amount of heat required to raise the temperature of 1 kilogramme (1 litre) of water 1° Cent., this unit has been adopted in Junker's Calorimeter.

If British Thermal Units are required, the result in calories has only to be multiplied by the factor 4 (more correctly 3·9683).

Taking the Reading

When the pointer of the gas meter passes zero, or a whole figure, shift the hot water tube from over the funnel into the measuring glass, and note the temperature of the hot water thermometer at five or six intervals while the glass is being filled. The cold water thermometer will generally remain stationary, and need only be observed once. As soon as the hot water reaches the two-litre mark, turn the gas off, and read the quantity of gas shown by the meter.

The following readings will serve as an example :—

Gas Meter	Cold Water Thermometer	Hot Water Thermometer	Water
5 cub. ft.	8·77°	26·75°	—
—	,,	26·70	—
—	,,	26·82	—
—	,,	26·80	—
—	,,	26·75	—
5·344 cub. ft.	8·77	26·80	2 litres
Gas burnt 0·344 cub. ft.	8·77° average	26·77° average	2 litres

A calorie being the quantity of heat required to raise the temperature of 1 litre of water 1° Cent., the experiment will

show the heating value of the gas by means of the following equation:

$$H = \frac{W\,T}{G};$$

where H is the calorific value of one cubic foot of gas;

W is the quantity in litres of water heated;

T is the difference of the temperature in degrees Centigrade of the inflowing, and of that of the outflowing, water;

G is the quantity in cubic feet of gas burned during the experiment.

$W = 2$ litres, $T = 26{\cdot}77^\circ - 8{\cdot}77^\circ = 18^\circ$;

$G = 0{\cdot}344$;

and $H = \dfrac{2 \times 18}{0{\cdot}344} = 104{\cdot}65$ calories.

A cubic foot of this gas would therefore have a calorific value of 104·65 calories.

It should be observed that this is a 'gross' value, which represents the total heat generated by the flame, including the whole of that of the hydrogen contained in the gas, which in the calorimeter is converted into water, and gives up its latent heat to the circulating water.

It is therefore of importance to ascertain the 'nett' calorific value of the gas used in such processes, which in many cases is 10 per cent. less than the gross value. The calorimeter gives a ready method of determining the difference between these gross and nett values, as we have only to measure the quantity of water condensed in the apparatus and collected in the small measuring glass. For every cubic centimeter of this water, an allowance of 0·6 calorie must be made. As the quantity of water produced is proportionally small, it is advisable to burn a large quantity of gas, say 2 to 3 cubic feet, for these determinations. Supposing 2 cubic feet of gas condensed 53 c.c. of water, we should ascertain the calorific value of the latent heat of the condensed water, thus:—

$$\frac{0{\cdot}6 \times 53}{2} = 15{\cdot}9 \text{ calories}$$

which should be deducted from the gross value, leaving the nett calorific value equal to 88·75 calories per cubic foot.

Professor William Robinson, assisted by Mr. Alfred Hay, B.Sc., made with Junker's calorimeter a series of 130 calorimetric tests with Nottingham gas. The author was present and assisted during one test. All temperatures are given in Centigrade, the heating values in calories.

—	Temperature of Room	Temperature of Water Inlet	Temperature of Water Outlet	Rise in Temperature	Gas burned cub. ft. per Minute	Temperature of Products of Combustion	Condensed Water per. cub. ft. of Gas	Gross Calories per cub. feet	Latent Heat of Steam	Nett Calories per cub. foot
	°	°	°	°		°			°	
First day	21	15·322	26·113	10·79	0·0407	—	25·7	165·3	15·4	149·9
Second day	22·5	12·9	27·68	14·78	0·0584	—	27·4	165·9	16·4	148·5
Third „	17·5	13·71	28·6	14·89	0·1103	17·5	26·43	164·8	15·86	148·94
Fourth „	17·5	13·75	28·53	14·78	0·1103	17·4	26·43	165·6	15·86	149·74

During the first and fourth day, samples of the gas were analysed by Professor Frank Clowes, D.Sc. By calculation from analysis the heating value of the gas was ascertained to be 164 calories gross, which fairly agrees with the above results.

Professor Robinson has also made some careful tests of Dowson gas, of which the following table gives the results :—

Duration of Time	Temperature of Room	Temperature of Water Inlet	Temperature of Water Outlet	Rise in Temperature	Gas Burned cub. ft. per Minute	Temperature of Products of Combustion	Condensed Water per cub. ft. of Gas	Gross Calories per cub. foot	Latent Heat of Steam	Nett Calories per cub. foot
Min.	°	°	°	°		°				
27	22	15·96	30·385	14·425	0·3056	19·6	2·73	37·56	1·63	35·93
10	23	16·10	28·65	12·55	0·2600	19·4	2·66	38·1	1·59	36·51
12	24	16·15	28·49	12·34	0·2633	19·5	2·6	37·17	1·54	35·63
12	24	16·2	28·9	12·7	0·2667	19·5	2·66	37·84	1·6	36·24
							Mean . .	37·7 − 1·6 = 36·1		

The gas was taken from the main supply to the engine during a run. Recently, by using a Shaw gas governor, much less variation is shown in the water outlet temperature, and the calorific value of the gas is thus exactly determined during the gas engine test.

CHAPTER XXXIII

DOWSON GAS

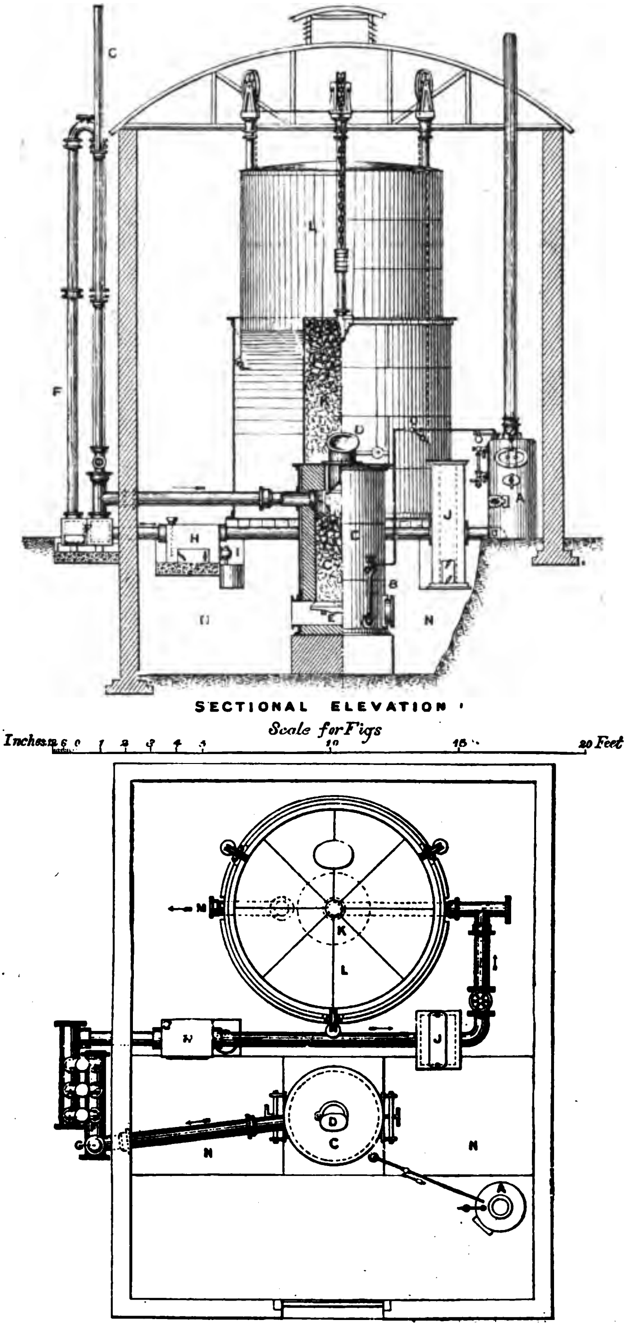
THE economical conditions of obtaining power from coal or coke are daily becoming more understood, and to obtain an indicated horse-power hour from one pound of coal is a great achievement; but that it has been done is indisputable, the credit for which must to a great extent be given to Mr. J. Emerson Dowson, who has designed a plant for the manufacture of producer gas, very suitable for a gas engine, with which the above result has been obtained. Dowson gas is made by forcing a mixture of steam and air through a mass of red-hot fuel, when not only is the steam decomposed into its constituent gases, oxygen and hydrogen, but a sufficiently high temperature is maintained in the generator to carry on the process continuously and make the gas as it is required by the gas engine.

A complete and compact set of his plant is shown at figs. 191 and 192, capable of generating sufficient gas for 80 E.H.P.

It consists of the boiler A, which is fitted with superheating tubes, B air injector, C gas generator, D feeding hopper, E fire bars, F gas cooler, G waste pipe, H hydraulic box, I overflow, J sawdust scrubber, K coke scrubber inside tank of gas holder, L gas holder, M outlet from gas holder to engine, N N ashpit for generator, O automatic regulator to govern production of gas.

The process is as follows. A current of superheated steam passes continuously, by a pipe from the top of boiler, through the injector, which consists of a nozzle inserted in the mouth of a conical tube, open to the atmosphere.

The pressure of steam varies from 30 to 60 lbs. per square inch above the atmospheric pressure, according to the size of the apparatus used and the quantity of gas required. This pressure forces the mixture of steam and air upwards, through the incandescent fire in the generator. The steam is decomposed in presence of the incandescent carbon, and the hydrogen, being free, passes off. The oxygen from the steam, as well as that from the air, combines in the first instance with the carbon of the fuel to form carbonic acid. As this rises through



FIGS. 191, 192. - DOWSON GAS PLANT FOR 80 H.P. (EFFECTIVE)

the hot fuel it is reduced to carbonic oxide. The liberated oxygen combines again, partly with some of the carbonic oxide, to become carbonic acid, and partly with carbon to form carbonic oxide.

The gas used in the internal combustion engine should be clean and free from sulphur compounds, and it must be cooled to give a large amount of energy per unit volume in the cylinder. Hence, for such purposes, it is best to use anthracite coal, which, being nearly pure, does not contain sulphur nor yield much ammonia, tar, or other products which readily condense and foul the pipes and valves. Good anthracite is also suitable fuel for the generator, because it makes a dense fire, free from holes or passages, and it does not cake or yield much clinker. Ordinary gas coke in small pieces free from sulphur, which does not yield large quantities of clinker and which has been subjected to high temperatures in the retorts, is also used with good results. The gas is cooled by passing through the pipes F, then cleansed by passing through water in the hydraulic box H, then through the sawdust scrubber J on its way to the coke scrubber K inside the gas holder. The automatic regulator O regulates the supply of steam to the generator and, within certain limits, governs the production of gas, by the rise or fall of the gas holder, and this not only avoids waste of fuel, but renders the storage of much gas unnecessary, as the production of gas is very rapid.

Carbonic oxide is a very poisonous gas, and devoid of colour, whilst having great heating power; but Dowson gas has a characteristic though very slight smell, not readily detected, but, with the proper precautions of sound fittings the risk is reduced to a minimum.

Unfortunately for Mr. Dowson, gas engine makers have not paid sufficient attention to the construction of engines to deal with producer gas to the best advantage. It is beyond dispute that good results are obtained from producer gas, even when using coke. The cost of maintenance of a boiler has long been known and accepted as inevitable. We may also accept the cost of a gas-producer plant, for a gas engine, though the up-keep will be less.

About four times the amount of Dowson gas is required than lighting gas in each charge which enters the cylinder of the gas engine.

A safe rule for the size of gas supply pipe is one third of a square inch for each indicated H.P. when working under ordinary conditions. The ordinary method of mixing gas and air gives the best results with producer gas, though necessitating a specially constructed channel. The difficulty with producer gas is to get enough into the cylinder, with the required volume of air; as the port in the cylinder is open for the same time as for town gas, it is important that the gas passages should be as free as possible, and that the valve should admit fully the extra quantity of gas. To ensure good working more 'lead' is necessary with Dowson than with coal gas.

The usual practice of regulating the air inlet near the combustion chamber does not give the best results, which the author has obtained by throttling the air at the extreme end of the air pipe and depending on the momentum generated in the column of air contained in the length of pipe when the piston is at its maximum velocity. By this method the gas is allowed to enter the combustion chamber freely and thoroughly mingle with whatever burned gases the cylinder may contain; when, towards the end of the charging stroke, the piston speed lessens, there is considerable commotion in the air pipe, which assists the incoming gas thoroughly mingling with it.

With an engine having a cylinder 19 × 30 inches stroke the author has found that the valves require cleaning, &c., as follows:

Exhaust valve required cleaning and grinding in every six weeks.

Air valve required cleaning and grinding in every six months.

Gas valve required cleaning and grinding in every two weeks.

This engine runs about 56 hours per week, and develops about 80 per cent. of its maximum power.

CHAPTER XXXIV

MANSFIELD OIL GAS

MESSRS. Mansfield & Sons are makers and patentees of plants for making cheap gas from oil, sawdust, nut shells, mineral, vegetable, and animal matter.

The Mansfield oil gas apparatus is shown at fig. 193. The producer or gas generator has a strong cast-iron casing D, lined inside with moulded fire clay blocks. The cast-iron retort C hangs by a flange on the fire clay cover, and can be lifted out or replaced in a few minutes. The retort is heated and kept up to the desired temperature, from 1,600° to 1,800° F., a bright cherry red, by a fire of coal, coke, wood, or other fuel, placed on bars at L and regulated to a nicety by the sliding grids M, the colour of the retort being observed through a sight hole. These retorts usually last two years with moderate use, and the clay blocks last for some two or three years. The trouble of screwing up and making joints in the ordinary way is obviated by the simple expedient of a socket in top of the retort, filled with melted lead, and a socket on top of the standpipe at N, kept filled with water. These are arranged to prevent the escape of gas, acting at the same time as safety valves, because, whenever any extraordinary back pressure occurs, the gas forces its way out at N or J. The lower end R of the standpipe dips into water in the hydraulic box G, which is regulated by the half-inch siphon bend J. Any accumulation of tar can be cleared out occasionally at the door K.

To make gas, the usual procedure is to light the fire below the retort and keep up a regular heat until the lead in the ring space C on the top of the retort is all melted, a sign that a sufficiently high temperature has been attained for the manufacture of the gas.

The can or cistern A is filled with oil or melted fat, which trickles into the funnel and through the half-inch siphon pipe B in a thin, continuous stream, one-sixteenth of an inch thick, into the upper part of the retort. The oil is vaporised in this pipe, and the oil vapour, passing down the interior into contact

with the sides of the retort, a cherry red heat, is decomposed or converted into 'fixed' gas. The gas, after leaving the retort, passes through the bonnet E, down the standpipe F, into the water in the hydraulic box G, where tarry or other

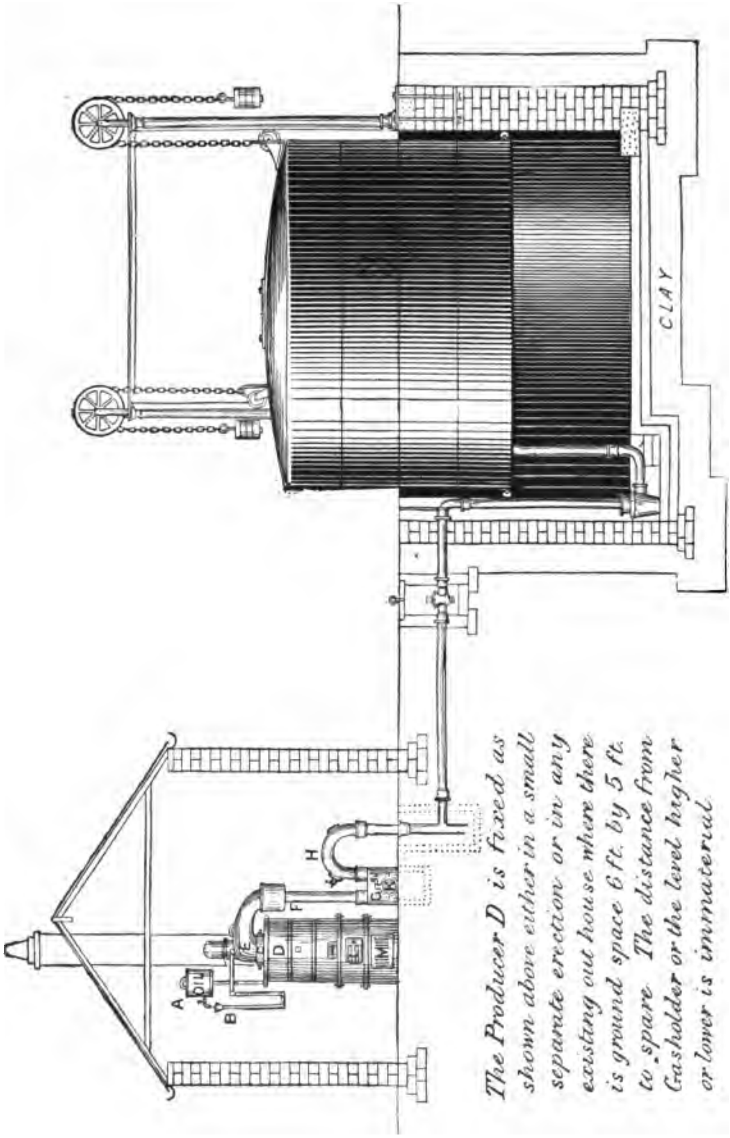


FIG. 193.—MANSFIELD'S OIL GAS APPARATUS

condensable products are separated, and thence by the arch pipe H and connecting pipes to the gas holder, where it is stored, and when cool is ready to be used for heating or motive power, without any further treatment being necessary.

A gentle pulsation of the lead at C, and in the water at N and J, is an indication of successful gas making, and the quality of the gas can be roughly tested at the small tap in the arch pipe H.

To stop gas making turn off the oil tap and remove the oil cistern from its stand. Let the fire cool down gradually, keeping the furnace door closed about fifteen minutes. Shut the main cock leading to the gas holder. Then, before the lead sets, lift out the bonnet E, any residual gas being allowed to burn; and, when cool, the retort, bonnet, and standpipe can be examined and cleared out, if necessary, with a scraper.

In the United Kingdom the oils mostly used are the Scotch intermediate oils, so called because in flashing point and density they lie between burning oils and lubricating oils. This refuse of heavy paraffin from the Scotch distillers is of specific gravity 0·840 to 0·865, and lowest flashing point (close test) 235° F. or 105° C. The oil is inexplosive and free from offensive smell. The Mansfield apparatus makes 1,000 cubic feet of gas from 7 to 9½ gallons of intermediate oil, which costs 5*l.* per ton, or about 4½*d.* per gallon. The cost of fuel in the furnace comes to less than 1*d.* per 100 cubic feet of gas made (on a moderate scale), so that the total cost of fuel and mineral oil to make gas is about 6*d.* per 100 cubic feet.

Messrs. Crossley state that with their 12 H.P. NOM. engine the consumption of the Mansfield oil gas is 9 cubic feet per I.H.P. hour; and the total cost of fuel used by the combination of engine and oil gas plant with intermediate oil is about ½*d.* per I.H.P. hour.

It is stated that an engine developing 13 I.H.P. with ordinary coal gas will develop more than 17 I.H.P. with oil gas.

In Russia the black crude oil, worth 10*s.* per ton, yields 80 to 90 cubic feet of good lighting or motor gas per gallon.

Mansfield Sawdust Gas Apparatus

Fig. 194 is a sectional elevation, and fig. 195 a plan, of the Mansfield Sawdust Gas Apparatus, suitable for making gas from sawdust, shavings, wood débris, mineral, animal, and vegetable matter.

To make gas, the material for heating the retorts—by preference coke or coal—is introduced into the furnace, and the vegetable refuse to be operated upon is fed into the hoppers. The regulation of atmospheric air for the combustion of the heating fuel is effected by sliding doors. The heated gas from the furnace, in the form of carbon monoxide, passes from the furnace into the combustion chamber, where it meets a quantity of air, which passes in from the outside of the apparatus through regulated doors. The heated gas, on coming in contact with this supply of air, takes fire, afterwards passing over the partition walls, whence they emerge by a series of passages into the chimney flue, and so pass away to the outer atmosphere.

The following experiments have been made in the carbonization of mixed sawdust :—

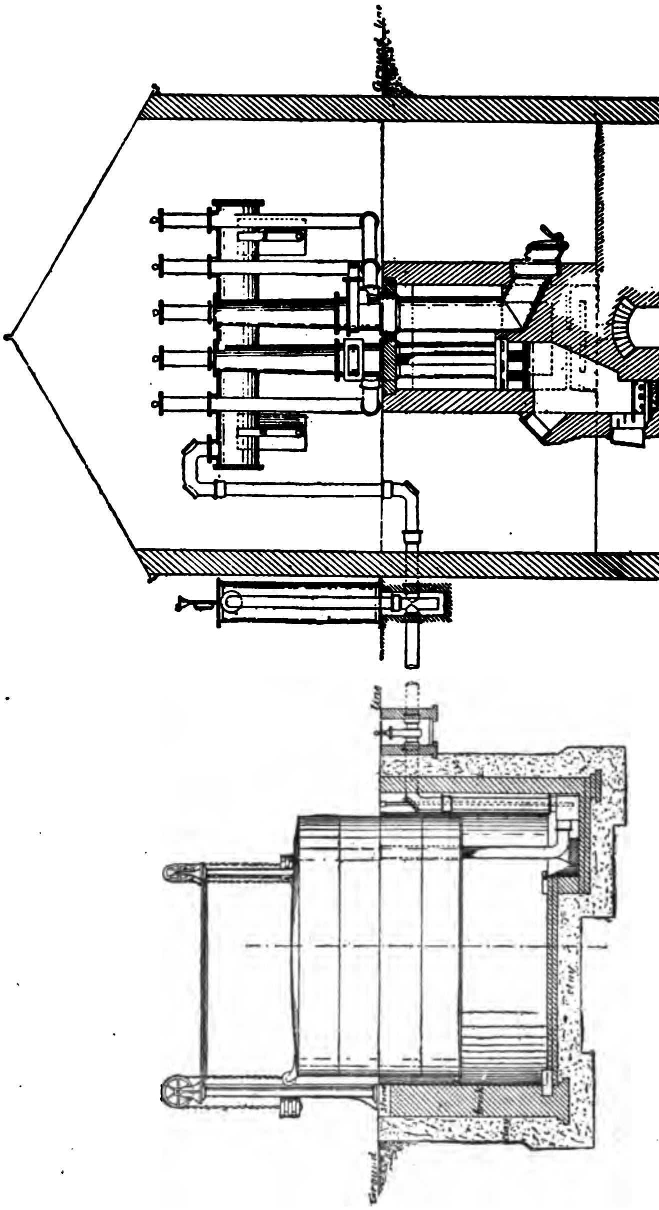
Gas made per ton of sawdust, not purified, but corrected for temperature and pressure = 18,292 cubic feet;

Illuminating power of the gas, 4·73 candles;

Illuminating power of the gas after passing through lime hydrate, 15·61 candles.

Cost of Carbonizing Sawdust

	s.	d.
1 ton of sawdust, producing 18,000 cubic feet of gas—say	2	0
Coke used to carbonize 1 ton of sawdust = 560 pounds at 10*s*. per ton	2	6
Labour—say		6
	5	0



ELEVATION.

FIG. 194.—MANSFIELD SAWDUST GAS APPARATUS

In addition to the large yield of gas, 1 ton of sawdust produces on an average 9·88 cwt. of pure powdered charcoal, for which a ready market should be found at about 30*s*. per

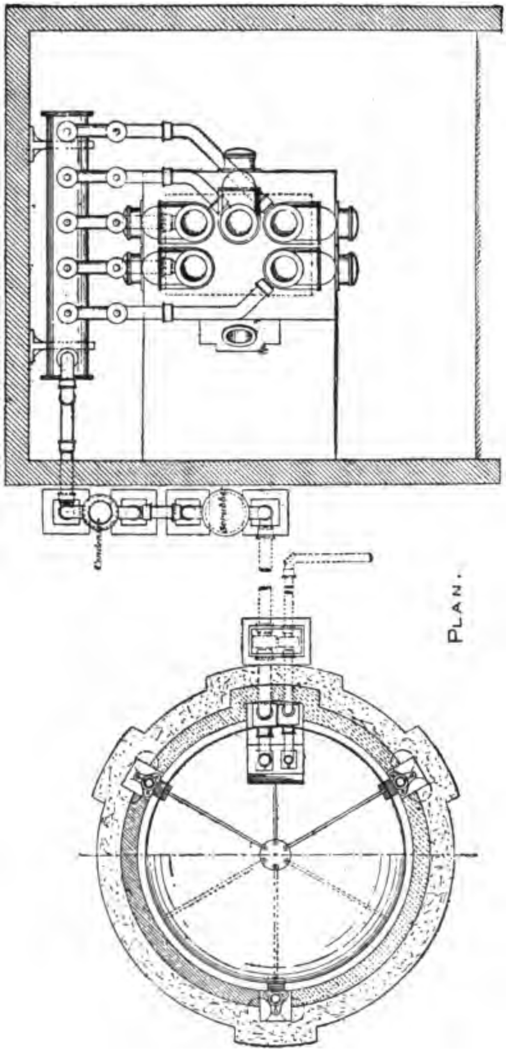


FIG. 195.—MANSFIELD SAWDUST GAS APPARATUS

ton. The gas has been tested with one of Messrs. Crossley's 4 H.P. NOM. engines, consuming 37·5 cubic feet of unpurified gas and 39·8 cubic feet of purified gas per B.H.P. hour.

Carbonization of Irish Bog

Irish bog carbonized = 42 lbs.

Gas made = 325·2 cubic feet corrected.

Time to carbonize 42 lbs. of bog = 1 hour 55 minutes.

Gas made per ton of bog = 17,344 cubic feet corrected.

The illuminating power of the gas after passing through a lime purifier on its way to the gas holder = 12·06 candles.

The volume of gas was corrected to 60° Fahr. and 30 inches of mercury pressure.

The illuminating power of the gas was tested by Dr. Letheby's Photometer. A 'D' argand burner was used, having fifteen holes and a 7 chimney. The gas was corrected to 5 cubic feet per hour, and also for temperature and pressure.

CARBONIZATION OF SUNFLOWER SEED SHELLS

Charges	Heat of Retort	Weight of Seed Shells Carbonized	Quantity of Gas made	Time occupied in Carbonizing each charge	Illuminating Power	
					Without Lime Purification	With Lime Purification
		lb.	Cubic feet	Minutes	Candles	Candles
First	Good Red	8	67·16	17		
Second	"		66·00	19		
Third	"		66·30	19	6·43	15·74
Four	"	8	66·49	18		
Fifth	"	8	65·00	20		
Totals of five charges . .			330·95	93		
Average for each 8 lb. . .			66·19	18·6		

Gas made per ton (corrected for temperature and pressure), 18,534 cubic feet.

Charcoal made per ton, 1·25 cwt.

In fine particles sulphuretted hydrogen was present in the gas at the outlet of condensers, and the gas was consequently passed through oxide of iron. No lime was used before passing the gas into the gasholder. The illuminating power of the gas corrected to 5 cubic feet per hour and for temperature and pressure. The gas was passed from the gasholder through a purifier filled with lime to free it from carbonic acid[1] (CO_2);

[1] The unpurified gas is quite as good for driving gas engines as it is after purification by lime.

after which the illuminating power of the gas (free from carbonic acid) was 15·74 candles, corrected to 5 cubic feet per hour and for temperature and pressure.

In testing the illuminating power of the gas a 'D.' Argand burner was used, having fifteen holes and a 7″ × 1¾″ chimney.

Analysis of the Sunflower Seed Shells Gas Unpurified

Carbonic acid	15·4 per cent.
Oxygen	Nil
Hydrocarbons	4·4 per cent.
Carbonic Oxide	23·7 per cent.

Messrs. Mansfield have made some experiments with refuse of olives, the crushed pulp left after olive oil is all pressed out. The yield equalled (15 candle power gas) 9,000 cubic feet per ton. These results are exceedingly good.

Messrs. Mansfield commenced making oil gas apparatus as far back as 1873. It is undoubtedly the longest lived and known oil gas apparatus system, and is in use nearly all over the world.

CHAPTER XXXV

THE THWAITE MOTOR GAS PLANT

THE gas-making plant associated with the name of Mr. Dowson is useful only where fixed carbon fuels, such as anthracite and best coke, are used; this, however, precludes the utilisation of soft bituminous coal, and other cheap fuels. But Mr. Thwaite has designed a three cycle plant for this purpose. Fig. 196 shows a general arrangement of a plant erected under this system; fig. 197 elevation of (A) non-reversal cycle; fig. 198 sectional elevation; and fig. 199 sectional elevation of (B) non-reversal cycle.

The Thwaite non-reversal cycle is effected in the two forms of plant marked by the figures 197, 198, and 199.

It will be seen that, as in the Thwaite Duplex Cycle, there are two vessels, connected at their upper part by means of a

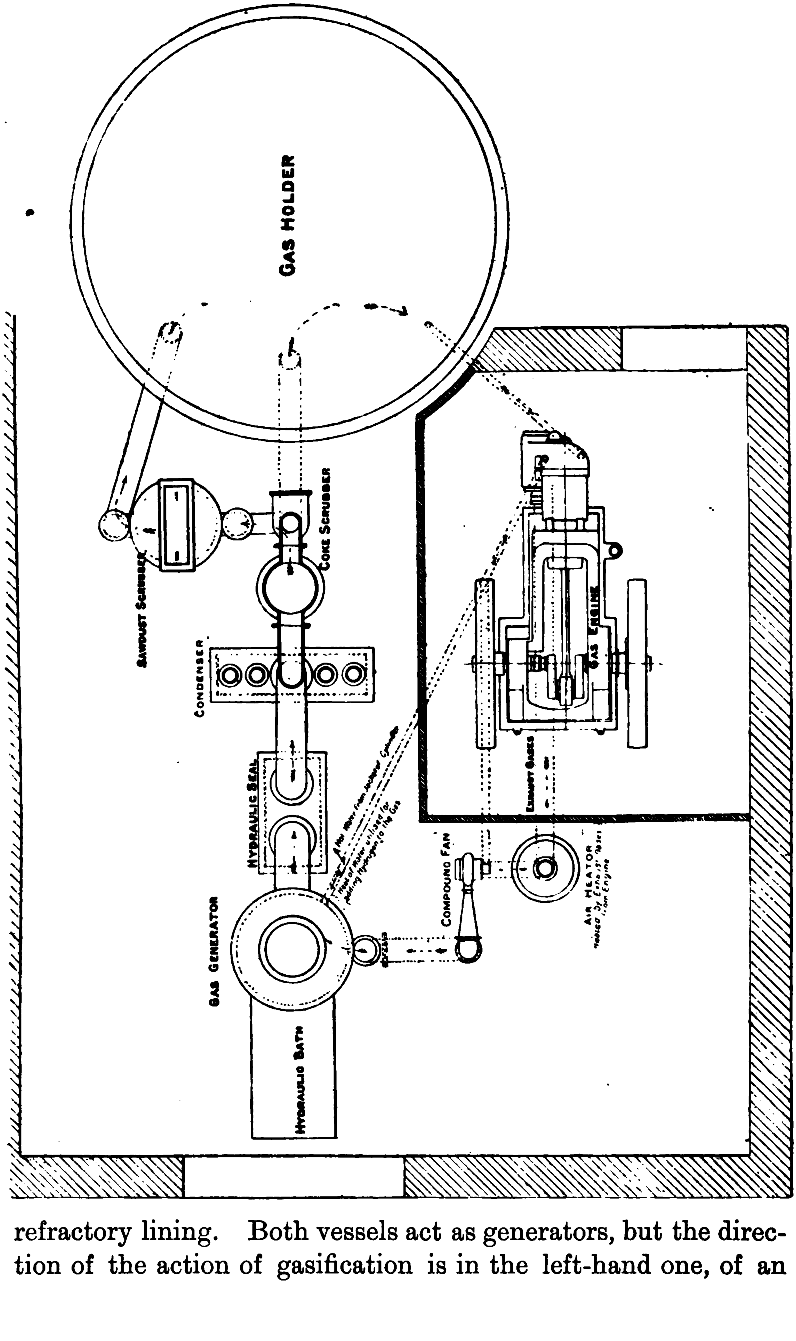


FIG. 196.—GENERAL ARRANGEMENT OF THWAITE MOTOR GAS PLANT

refractory lining. Both vessels act as generators, but the direction of the action of gasification is in the left-hand one, of an

ascensional character, whereas in the right-hand vessel the direction of action is descensional. An air blast is introduced under the grate of the left-hand vessel, through the hydraulic bath of which it has to permeate. In its flow it takes over a certain proportion of moisture; this is evaporated in contact with the incandescent fuel, and is eventually converted into hydrogen.

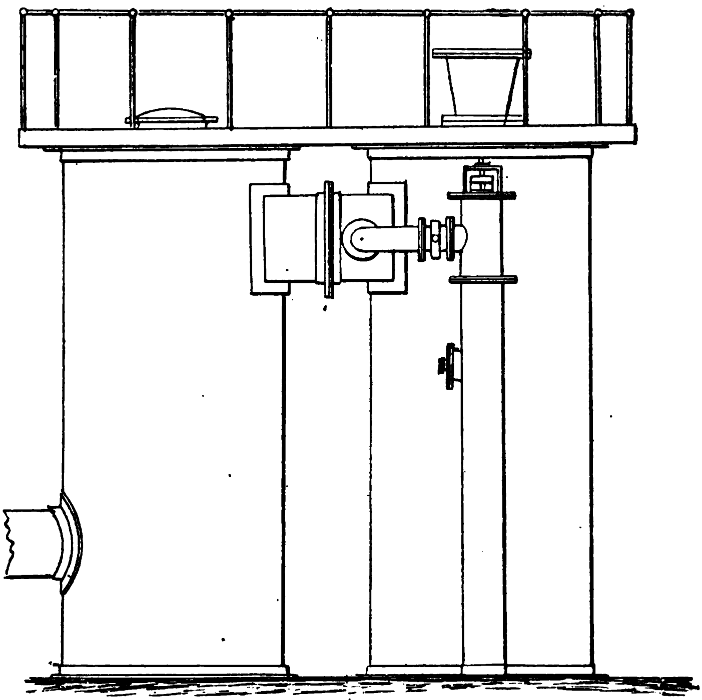


FIG. 197.—ELEVATION OF THWAITE'S (A) NON-REVERSAL CYCLE GAS PLANT

The air blast passes through the hanging fire-bars, suspended from a hanging cone B, carried by the brackets C that are bolted to the castings D.

A secondary air supply is supplied to the fuel through the circular flue, from which it enters the fuel in well-distributed jets. A third air supply, if necessary, is supplied to the refractory lined main connecting the two vessels.

The moistened air blast entering the base of the left-hand

vessel, in passing through the fuel, becomes converted, in conjunction with the fuel, into carbon-monoxide, hydrogen, and nitrogen.

The secondary air blast partly consumes this gaseous fuel, and along with it the gases evolved from the hydrocarbons of the newly introduced coals. If necessary the flame action is

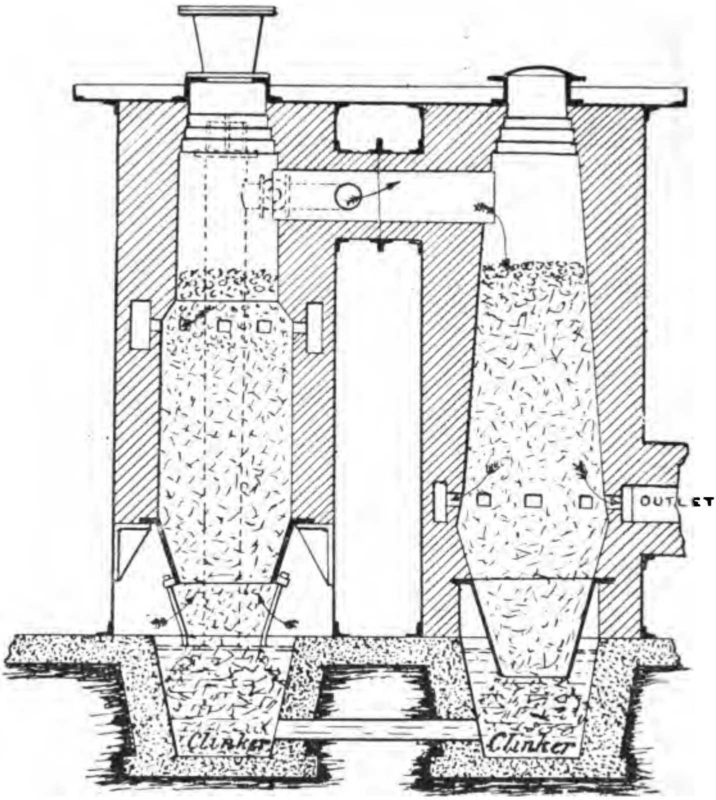


FIG. 198.—SECTIONAL ELEVATION OF THWAITE'S (A) NON-REVERSAL CYCLE GAS PLANT

intensified by the tertiary supply of air. The flame, in descending through the mass of fuel in the second vessel, raises the coal therein to a state of incandescence, and in passing descensionally through this heated carbonaceous column of fuel, the products of combustion of the gases generated in the first vessel are reconverted into carbon monoxide and free hydrogen. The

hydrocarbons of the fuel fed into both vessels are either oxidised or burnt by the supply of air, but the products of combustion are reconverted into C, O, and H, or if they descend through the incandescent column of fuel, they are split up by thermolytic action, the hydrogen being set free and the solid carbon remaining to be converted into carbon-monoxide. The gases

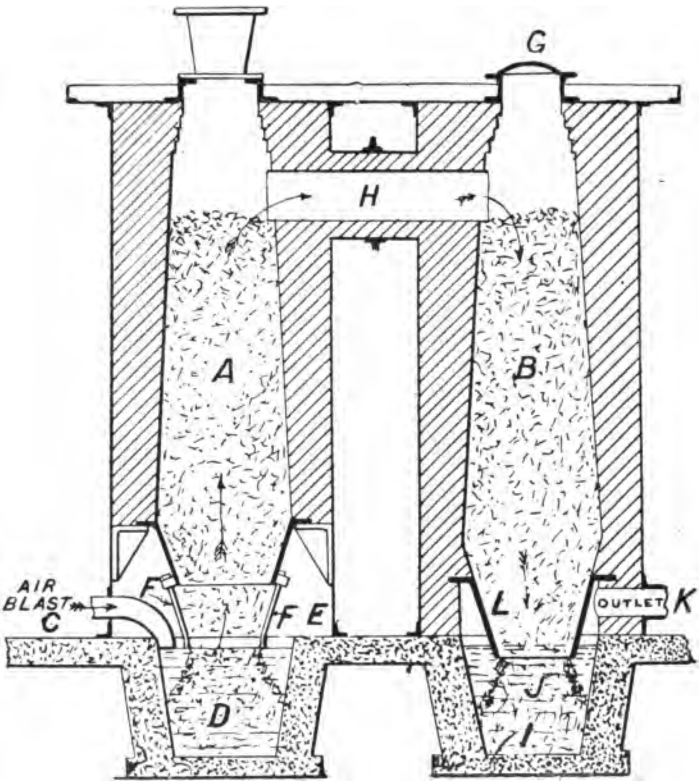


FIG. 199.—SECTIONAL ELEVATION OF THWAITE'S (B) NON-REVERSAL CYCLE GAS PLANT

escape by the flues. The clinker and ash gravitates to the water base, from which they can be drawn away at any time. By this (A) non-reversal cycle any kinds of rich bituminous coal can be used for gas engine purposes. By the combined action of oxidation and thermolysis, the hydrocarbons are converted into fixed and non-condensible gases. Although this cycle is

not so ingenious nor so perfect as the reversal one, it nevertheless enables common bituminous fuels to be used, and the plant is rather less expensive in cost of construction.

The Thwaite (B) non-reversal cycle plant is shown in fig. 199. The two vessels are connected together by an upper connecting conduit. A is the active generating vessel, B the direct scrubbing and dust-catching vessel. The air is introduced by the dip pipe C and is compelled to flow through the water D, entering into the cavity E, from which it enters the fuel between the hanging bars F; the blast, carrying suspended moisture, flows through the fuel G, and the carbonic oxide and hydrogen gases pass through the connecting conduit H into the second vessel B, filled with coke, or even coal, because the sensible heat of the gases in the first vessel is sufficient to volatilise some of the higher olefiants of the hydrocarbons. The gases, along with the hydrocarbons that may be volatilised, flow descensionally through the coke in the second vessel, the tarry suspended matters being separated in their descent. The coke in the second vessel rests on the solid hearth I, where it is submerged in water J. The gas is compelled to flow through this water before it can escape by the outlet pipe K, because of the dip inverted cone L, and in its flow through this water the remaining sensible heat is, to a great extent, recovered by the water in the hydraulic bath. The heated water in the bath flows direct into the water bath of the second vessel, so that the steam arising in the first vessel passes into the fuel and increases the proportion of hydrogen in the gases produced. For some coals there will be no necessity to employ any further purifier than this second vessel. Any dirt or dust introduced into the first vessel with the coal is caught in the second vessel. The dirty coke or coal in the second vessel gradually gravitates to the base, and can be withdrawn without arresting the production of gas. The tarry matters are partially washed out of the coke when it gravitates to the base. The tar can easily be recovered from the hydraulic bath.

This B cycle is the ideal one for using gas, coke, or fine anthracite, because with the single vessel the fine sulphur dirt or carbon is carried forward, at the velocity of the gases, into

the mains, and tends to clog them up. It is also an admirable plant for steam coals containing only a low proportion of hydrocarbons; and coals with even a high proportion of hydrocarbons can be successfully used with this B cycle plant.

The coke for the second vessel is introduced by a retort type of hopper K.

Abstract of Report on Experiments made at the Motor Gas Plant Syndicate's Demonstration Station at Stoke Newington, on their Thwaite 'Simplex' and 'Duplex' Motor Gas Producers, with various kinds of fuels. By MR. GEORGE CAWLEY, M.I.M.E.

'The comparative efficiency of the gas plant is most conveniently expressed by stating the required *weight* of any given fuel to produce one *indicated* horse-power per hour in the gas engine. The fuels used are anthracite, steam coal, slack, and coke. In the "Simplex" producer the fan blast is introduced above the grate level, and it passes up through the body of the fuel to form "producer gas." In the "Duplex" producer, instead of the gas passing off direct from the top, it is made, after being first formed in one cupola, to pass down through the incandescent fuel in the other, the object aimed at being the conversion and utilisation of the crude tarry hydrocarbon vapours, evolved in the first cupola, into a permanent gas. In order that this action may go continuously it is arranged that the direction of flow of blast and gas may be reversed at frequent intervals. This is effected automatically by means of a hydraulic tumbler. In this way a gas is made suitable for gas engines from bituminous coal or even from slack of indifferent quality.

'In the "Simplex" producer the fan blast is introduced above the grate level, and it passes up through the body of the fuel to form "producer gas."

'In the "Duplex" producer, instead of the gas passing off direct from the top, it is made, after being first formed in one cupola, to pass down through the incandescent fuel in the other, the object aimed at being the conversion and utilisation of the

crude tarry hydrocarbon vapours, evolved in the first cupola, into a permanent gas. In order that this action may go on continuously it is arranged that the direction of flow of blast and gas may be reversed at frequent intervals. This is effected automatically by means of a hydraulic tumbler.

'PRELIMINARY MEASUREMENTS AND CALIBRATIONS

'*Fuel.*—The density of the four fuels—namely, anthracite, steam coal, slack, and coke—were determined in the following manner.

'An empty galvanised iron pail was weighed on a spring balance, and its weight was noted. It was then filled with water, at a temperature of 60° Fahr., and again weighed. The nett weight of the volume of water contained in the pail was thus obtained. The pail was then filled with fuel, whose density was to be obtained, and the nett weight of the pailful of fuel obtained in a similar way.

If W = the nett weight in lbs. of a pailful of water at 62° Fahr.;

F = the nett weight in lbs. of a pailful of the fuel;

C = the weight of a cubic foot of water at 62° Fahr.;

D = the weight of a cubic foot of the fuel in lbs.;

Then $D = \frac{F\,C}{W}$.

'*Description of fuels used.*—The anthracite was stated to be "Hendreforgan Anthracite"; the steam coal "Brethy Steam Nuts"; the slack was a very common slack from the Wigan district; and the coke was the usual quality gas-works coke.

'*Spring balances.*—The Salter spring balances used on the engine friction brake, and that used for weighing the fuel, were tested by hanging from them stamped scale weights, and were found to indicate correctly.

'*Large gas engine.*—The diameter of the piston and fly-wheels and the length of the stroke were ascertained by actual measurement.

'*Boiler feed water.*—This was measured in a wrought-iron

tank, by computing the weight of water contained in it per inch of depth.

'*Gasholder.*—The vertical content scale affixed to the holder tank was calibrated by first emptying the holder to the zero point of the scale, and then passing successively 100 cubic feet volumes of town's gas into it, as measured by the gas meter in the engine house. After the passage of each 100 cubic feet, a mark was made on the scale, and the divisions thus made were afterwards divided into tenths, corresponding to volumes of ten cubic feet.

'*The indicator.*—A Tabor indicator was used to determine the indicated horse-power, and was carefully cleaned and oiled before each series of diagrams were taken.'

'METHOD OF CARRYING OUT THE TESTS

'The results aimed at were briefly:—

'1. To determine the volume and temperature of gas made per pound of fuel supplied to the producer.

'2. To determine the power-producing quality of the gas made during a given test, by passing it through the gas engine under ordinary working conditions, and noting the cubic feet of gas consumed per indicated and brake horse-power per hour.

'To obtain result 1 involves the determination of the weight of the fuel consumed in the producer during a given time; and to do this accurately it is necessary that the weight of fuel in the producer at the beginning and end of the test should be determinable.

'In the Simplex producer the maximum percentage of error would be $\frac{40 \times 100}{W}$, where W is as before the total weight of fuel consumed during a given test.

'In the eight hour tests referred to in this report the error due to gauging is not likely to exceed 8 per cent. The other determinations necessary to obtain results 1 and 2 offered no special difficulty, and the results obtained are within the usual limits of accuracy.

'The fuel charged into the producers was carefully weighed in 10 lb. lots in an iron pail upon a small Salter's spring balance, graduated up to 15 lbs.

'The volume of gas coming from the producer was measured by a holder scale every quarter of an hour.

'The method adopted for testing the quality of the gas in the gas engine was the following :—When the friction brake and indicator gear were fully arranged, the supply of town's gas was shut off from the engine, and the producer gas, stored in the holder, introduced in its place. This change of gas necessitated some adjustment of the air supply valve and sparking arrangement; and when this was effected, and the engine running at its maximum power, the gas quality test was commenced at a given signal, when three assistants attended to the following matters. One put the revolution counter gear, having previously noted its figures; another made a pencil mark on the tape of the explosion recorder just below the gripper rollers; while the third noted the volume of gas in the holder. The brake test was continued for fifteen minutes exactly, during which time ten indicator diagrams were taken, and an equal number of readings taken from the spring balances of the friction brake. At the end of the quarter of an hour, and at a given signal, the revolution counter was drawn out of gear, the explosion recorder tape again marked, and the volume of gas taken from the holder during the test noted. From the data thus obtained the volume of gas required for each indicated and brake horse-power per hour was determined, and also the mean number of revolutions of the engine per minute, and the number of "miss-fires" of the explosive gases admitted to the cylinder.

'The accompanying tables referring to each day's test show, in a detailed manner, the general results obtained. As the fan for providing the producer blast would be in ordinary practice driven by the main engine using power gas, I have assumed that it was so driven, and that one brake horse-power is required to drive it. This is amply sufficient, as shown by the consumption of town's gas in the small gas engine now driving the fan. An allowance has been made for the fan on this

basis, in determining the coal used per indicated horse-power per hour in the large engine.'

TABLE 1A

'Experiments on the "Duplex" Gas Producer using Steam Coal as Fuel, and Fan-blast

GAS VOLUME TEST

Date of trial	April 2, 1895
Time of trial	10 A.M. to 6 P.M.
Duration of trial	Eight hours
Condition of weather	Fine but cloudy
Average temperature of outside air	46° Fahr.
Average temperature of gas when entering holder	62° Fahr.
Pressure of gas in holder, in inches of water	1·5
Average pressure of crude gas in producer delivery-pipe, in inches of water	3·57
Density of steam coal used per cubic foot, in lbs.	47·18
Weight of steam coal per inch depth of both cupolas, in lbs.	13·88
Total volume of gas produced during trial, in cubic feet	34·020
Average volume of gas produced per hour, in cubic feet	4,252·5
Volume of gas produced per lb. of steam coal supplied, in cubic feet	54·04

TABLE 1B

GAS QUALITY TEST

Date of trial	April 2, 1895
Time of trial	7 P.M. to 7.15 P.
Duration of trial	Fifteen minutes
Diameter of gas engine cylinder in inches	$13\frac{1}{8}$
Length of stroke in inches	22
Length of 'working stroke' per revolution in inches	11
Nature of load on engine	Friction brake
Power	Engine running with gas inlet valve full open
Total revolutions of engine in fifteen minutes	2,625
Average revolutions of engine per minute	175
Mean effective radius of brake lever, in feet	3·03
Average nett load due to spring balances, in lbs. (I.)	$21\frac{5}{8}$
Brake horse power $\frac{2\ r\ n\ 1}{33,000}$	21·77
Number of indicator cards taken	10

Scale of indicator spring	$\frac{1}{80}$ inch
Average mean pressure, neglecting pumping stroke, in lbs. per square inch	46·35
Nett mean effective pressure after allowing for work done in pumping stroke, in lbs. per square inch	44·92
Average maximum initial pressure above atmosphere, in lbs. per square inch	156·8
Maximum possible explosions per fifteen minutes	1312·5
Maximum possible explosions per minute	87·5
Total actual explosions in fifteen minutes shown by explosion recorder	1,312
Average number of actual explosions per minute	87·46
Average indicated horse-power	29·54
Indicated horse-power capacity of producer as deduced from gas production test	54·10
Gas used by engine in fifteen minutes, in cubic feet	555
Gas used I.H.P. per hour, in cubic feet (including fan)	78·6
Coal required per I.H.P. per hour (neglecting fan) in lbs.	1·39
Coal required per I.H.P. per hour to drive fan (estimated)	0·07
Total coal required per I.H.P. per hour (including fan)	1·46

TABLE 2A

'Experiments on the "Duplex" Gas Producer, using Slack as Fuel and Fan-blast

GAS VOLUME TEST

Date of trial	April 3, 1895
Time of trial	11 A.M. to 7 P.M.
Duration of trial	8 hours
Condition of weather	Fine but cloudy
Average temperature of outside air	47° Fahr.
Average temperature of gas when entering holder	50·5° Fahr.
Average pressure of crude gas in producer delivery pipe, in inches of water	3·25
Density of slack used per cubic foot, in lbs.	48·18
Total nett weight of slack fed into cupolas during trial, in lbs.	542·25
Average nett weight of slack fed into cupolas during each hour, in lbs.	67·78
Total volume of gas produced during trial in cubic feet	23312·5
Average volume of gas produced per hour, in cubic feet	2976·56
Volume of gas produced per lb. of slack supplied, in cubic feet	43·91

TABLE 2B

GAS QUALITY TEST

Date of trial	April 3, 1895
Time of trial	7.15 P.M. to 7.30 P.M.
Duration of trial	Fifteen minutes
Diameter of gas engine cylinder, in inches	13⅛
Length of stroke in inches	22
Length of working stroke per revolution, in inches	11
Nature of load on engine	Friction brake
Power	Engine running with gas valve full open
Total revolutions of engine in fifteen minutes	2,466
Average revolutions of engine per minute (n)	164·4
Mean effective radius of break lever, in feet (r)	3·03
Average nett load due to spring balances, in lbs. (1)	205·35
Brake horse-power $\frac{2\ r\ n\ 1}{33{,}000}$	19·48
Number of indicator cards taken	10
Scale of indicator spring	$\frac{1}{80}$ inch
Average mean pressure, neglecting pumping stroke, in lbs. per square inch	46·53
Nett mean effective pressure, after allowing for work done in pumping stroke, in lbs. per square inch	45·08
Average maximum initial pressure above atmosphere, in lbs. per square inch	164
Maximum possible explosions in fifteen minutes	1,233
Maximum possible explosions per minute	82·2
Total actual explosions in fifteen minutes, shown by the explosion recorder	1,233
Average number of actual explosions per minute	82·2
Average indicated horse-power	27·69
Indicated horse-power capacity of producers, as deducted from gas production test	33·77
Gas used by engine in fifteen minutes, in cubic feet	580
Gas used by engine per hour, in cubic feet	2,320
Gas used per I.H.P. per hour, in cubic feet (including fan)	88·12
Slack required per I.H.P. per hour (neglecting fan), in lbs.	1·91
Slack required per I.H.P. per hour to drive fan (estimated)	0·10
Total slack required per I.H.P. per hour (including fan)	2·01

TABLE 3A

'Experiments on the "Simplex" Gas Producer, using Coke as fuel, and Steam-blast

GAS VOLUME TEST

Date of trial	April 1, 1895
Time of trial	10.45 A.M. to 4.45 P.M.
Duration of trial	Six hours
Condition of weather	Cloudy with occasional showers
Average temperature of outside air	47° Fahr.
Average temperature of gas when entering holder	81·9° Fahr.
Pressure of gas in holder, in inches of water	1·5
Average pressure of crude gas in producer delivery pipe, in inches of water	4·41
Density of coke used per cubic foot, in lbs.	27·25
Average net weight of coke fed into cupola during each hour, in lbs.	73·87
Total volume of gas produced during trial, in cubic feet	37,485
Average volume of gas produced per hour, in cubic feet	6,247·5
Volume of gas produced per lb. of coke supplied, in cubic feet	84·57
Weight of steam used for steam blower during trial, in lbs.	450
Weight of steam used for steam blower per hour, in lbs.	75
Estimated equivalent weight of coke to raise steam for steam blower in lbs.	90
Estimated equivalent weight of coke to raise steam for steam blower per hour, in lbs.	15

TABLE 3B

GAS QUALITY TEST

Date of trial	April 1, 1895
Time of trial	5.30 P.M. to 5.45 P.M.
Duration of trial	Fifteen minutes
Diameter of gas engine cylinder, in inches	$13\frac{1}{8}$
Length of stroke, in inches	22
Length of 'working stroke' per revolution, in inches	11
Nature of load on engine	Friction brake
Power	Engine running with gas valve full open
Total revolutions of engine in fifteen minutes	2,572

Average revolutions of engine per minute (n)	171·5
Mean effective radius of brake lever, in feet (r)	3·03
Average net load due to spring balances, in lbs. (l)	203·58
Brake horse-power $\frac{2\ r\ n\ l}{33,000}$	20·14
Number of indicator cards taken	10
Scale of indicator spring	$\frac{1}{80}$ inch
Average mean pressure, neglecting pumping stroke, in lbs. per square inch	46·2
Net mean effective pressure, after allowing for work done in pumping stroke, in lbs. per square inch	44·63
Average maximum initial pressure above atmosphere, in lbs. per square inch	182
Maximum possible explosions in fifteen minutes	1,286
Maximum possible explosions per minute	85·73
Total actual explosions in fifteen minutes shown by the explosion recorder	1,284
Average number of actual explosions per minute	85·6
Average indicated horse-power	28·71
Indicated horse-power capacity of producer, as deduced from gas-production test	64·52
Gas used by engine per hour in cubic feet	2,780
Gas used per I.H.P. per hour, in cubic feet	96·83
Coke required per I.H.P. per hour (neglecting steam blower) in lbs.	1·14
Coke required per I.H.P. per hour for raising steam for steam blower in lbs.	0·52
Total coke required per I.H.P. per hour (including steam blower) in lbs.	1·66

TABLE 4A

'Experiments on the "Simplex" Gas Producer, using Coke as fuel, and Fan-blast

GAS VOLUME TEST

Date of trial	April 4, 1895
Time of trial	10.15 A.M. to 4.15 P.M.
Duration of trial	Six hours
Conditions of weather	Dull, but fine
Average temperature of outside air	46° Fahr.
Average temperature of gas when entering holder	59·25° Fahr.
Pressure of gas in holder, in inches of water	1·5
Average pressure of crude gas in producer delivery pipe, in inches of water	4·21
Density of coke used per cubic foot, in lbs.	27·25
Weight of coke per inch depth of cupola, in lbs.	5·59
Total net weight of coke fed into cupola during trial, in lbs.	378·75

Average net weight of coke fed into cupola during each hour in lbs.	63·125
Total volume of gas produced during trial, in cubic feet	31,150
Average volume of gas produced per hour, in cubic feet	5,191·6
Volume of gas produced per lb. of coke supplied, in cubic feet	82·24

TABLE 4B

GAS QUALITY TEST

Date of trial	April 4, 1895
Time of trial	5 P.M. to 5.15 P.M.
Duration of trial	Fifteen minutes
Diameter of gas engine cylinder, in inches	$13\frac{1}{8}$
Length of stroke in inches	22
Length of 'working stroke' per revolution, in inches	11
Nature of load on engine	Friction brake
Power	Engine running with gas valve full open
Total revolutions of engine in fifteen minutes	2,703
Average revolutions of engine per minute (n)	180·2
Mean effective radius of brake lever, in feet (r)	3·03
Average net load due to spring balances, in lbs. (l)	183·33
Brake horse-power $\frac{2\ r\ n\ l}{33,000}$	19·06
Number of indicator cards taken	10
Scale of indicator spring	$\frac{1}{80}$ inch
Average mean pressure, neglecting pumping stroke, in lbs. per square inch	41·44
Net mean effective pressure, after allowing for work done in pumping stroke, in lbs. per square inch	40·7
Average maximum initial pressure above atmosphere, in lbs. per square inch	130·73
Maximum possible explosions in fifteen minutes	1,351·5
Maximum possible explosions per minute	90·1
Total actual explosions in fifteen minutes, shown by explosion recorder	1,333
Average number of actual explosions per minute	88·85
Average indicated horse-power	27·18
Indicated horse-power capacity of producer, as deduced from gas-production test	52·2
Gas used by engine per hour, in cubic feet	2,568
Estimated volume of gas required to drive fan, in cubic feet per hour	135
Gas used per I.H.P. per hour, in cubic feet (including fan)	99·45
Coke required per I.H.P. per hour (neglecting fan), in lbs.	1·15
Coke required per I.H.P. per hour to drive fan (estimated)	0·06
Total coke required per I.H.P. per hour (including fan)	1·21

Comparison of Fuel Consumption per I.H.P. per hour, between high-class Steam Engines and Boilers, and your Gas-producer Plant with a good Gas Engine

'In basing the comparison between the fuel consumption per indicated horse-power per hour, as given in diagram V., and that obtaining in modern high-class boilers and steam engines, perhaps the most reliable figures that can be taken to represent boilers and engines, as working in actual practice, are those given by the Research Committee of the Institution of Mechanical Engineers, in connection with the propelling machinery in the six steamers named as follows: "Meteor," "Colchester," "Tartar," "Fusi-yama," "Iona," and "Ville de Douvres." These figures refer to marine engines of fairly large power, and generally designed with a view to the promotion of economy of fuel. They may, therefore, be accepted as having a higher range of working economy than even the higher class of stationary steam engines of a power corresponding to that shown in the accompanying tables, which is in every case under 30 I.H.P. But in order to do full justice to the steam engine in this comparison, I will take the Research Committee's results as representing its economy.

'To form a fair comparison, it is well to at first consider the relative calorific values of the fuels used in each case. The mean equivalent carbon value of the various steam coals used by the Research Committee was 0·952. In the absence of calorimetric tests of the fuels used in your gas producers, I will assume the following equivalent carbon values, which, judging from former experiments, will be a fair approximation:—

	Assumed carbon values
Steam coal	1·000
Anthracite	0·920
Coke	0·900
Slack	0·820

'The Research Committee's results show that the fuel required in the six vessels above named was 2·06 lbs. per I.H.P.

per hour, as expressed in carbon value. If we take this weight as expressing the unit of economical efficiency for steam engines, the comparative efficiency of your plant is shown in the following table:—

COMPARATIVE EFFICIENCY AS REGARDS FUEL CONSUMPTION PER I.H.P. PER HOUR

Nature of Fuel	Steam engines and Boilers	Gas producer and Gas engine
Various steam coals . .	1·00	—
Steam coal. . . .	,,	1·34
Anthracite	,,	1·60 (?) (steam blast)
Coke	,,	1·80
Slack	,,	1·19 (fan blast)

'In connection with the above figures, it may be stated that they are strictly net, as regards your plant, for full allowance has been made in the way of fuel-equivalent for the steam and fan blast, and in computing the indicated horse-power from the indicator diagrams.

'I have purposely confined myself in the foregoing comparison to the relative weight of fuel alone.'

CHAPTER XXXVI

GAS ENGINE TESTS

THE author was pleased to receive an invitation from Professor Capper, to be present on January 10 and 11, 1895, when a 7 H.P. NOM. engine by Messrs. Crossley Bros. was tested in his laboratory at King's College, London, for purely scientific purposes.

I have Professor Capper's permission to publish the following report:—

In gas engine trials it has hitherto been usual to assume that the temperature of the explosive mixture during constant volume ignition varies directly as the pressure. As this treatment does not seem altogether justifiable, I have recently carried out a number of trials in my laboratory in which complete

gas and exhaust analyses have been made for me by Mr. G. N. Huntley, A.R.C.S., F.I.C.S., and the temperatures and heat additions have been calculated from the constants so obtained.

The following full-power trial will illustrate the method.

This trial was carried out on January 10, Mr. W. Norris, M.I.Mech.E., being present.

The engine was run in working condition, the last time it was disconnected for cleaning being some eight months before the trial.

Engine.—The engine is a 7 NOM. H.P. Crossley engine with tube ignition and loaded ball governor. It was built in 1892, and has been in constant use driving the workshops and running experimental trials ever since. Its cylinder is 8·5 inches diameter × 18 inches stroke. The clearance volume is ·2467 cubic feet.

Trial.—The trial on January 10 lasted forty minutes, indicator diagrams and all other observations being taken every five minutes.

Indicator Diagrams.—A Wayne indicator, calibrated under steam upon my mercury column, was used. For the power diagrams a $\frac{1}{120}$ spring and for the pumping stroke a $\frac{1}{10}$ spring was employed. From the indicator diagrams (see fig.

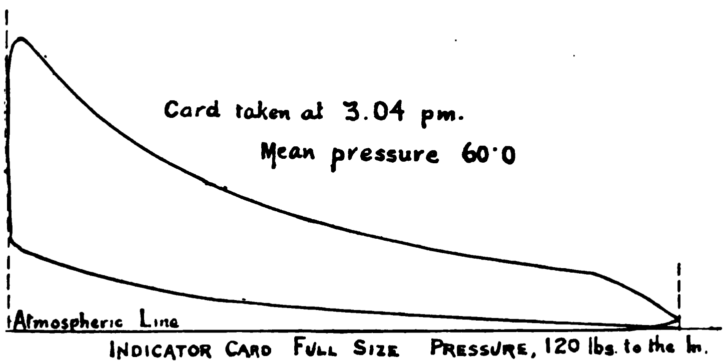


FIG. 200

200) which approached nearest to the average of the whole number taken, a mean diagram has been drawn on an enlarged scale, shown in fig. 201. A pumping diagram is shown, actual size, in fig. 202.

FULL POWER TRIAL

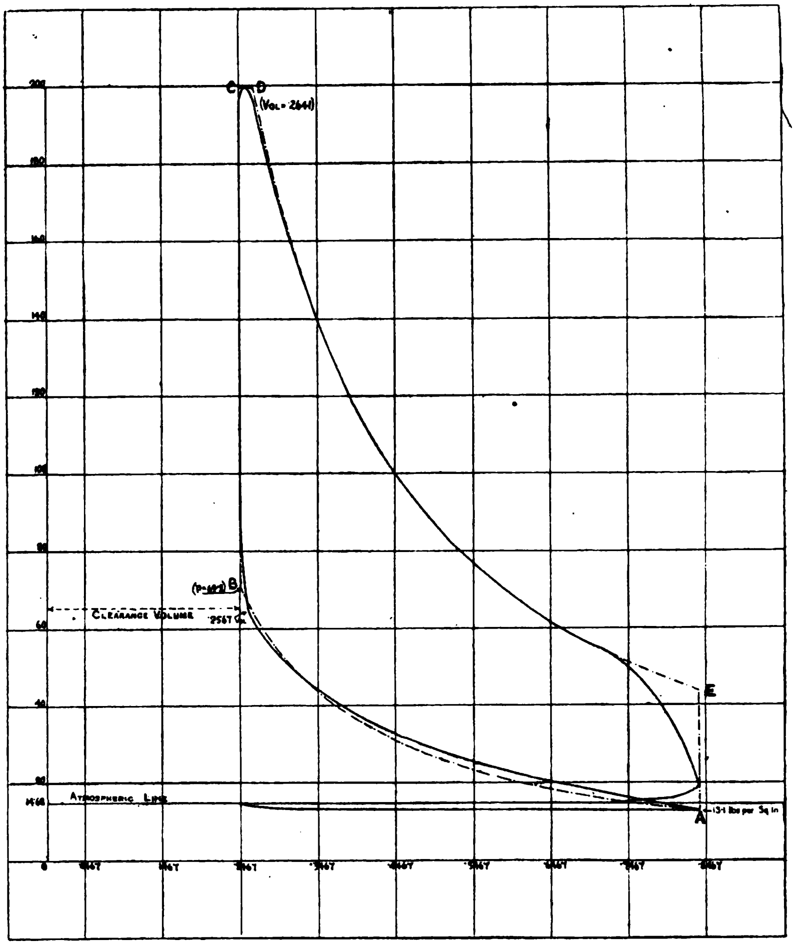
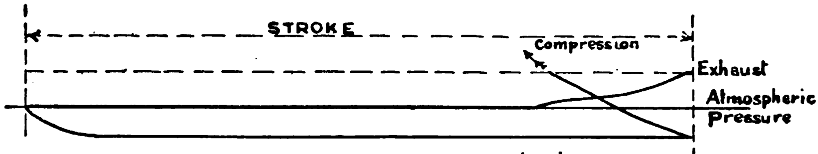


Fig. 201



PUMPING CARD. Pressure = 10 lbs to the Inch

Fig. 202

Brake.—A simple rope brake passed once completely round the flywheel, and to one end was attached a spring balance and to the other a dead load. The flywheel has an effective circumference of 17·458 feet.

Gas Meter.—The gas was measured by a standard meter made by Messrs. Alexander Wright & Co. for the Society of Arts motor trials. It now belongs to my laboratory and can be accurately read to $\frac{1}{100}$ of a cubic foot.

The ignition gas was measured through a smaller meter, which can be estimated to $\frac{1}{1000}$ of a cubic foot.

Sampling.—The gas was sampled by Mr. Huntley over water through a bye-pass close to the meter, a continuous sample being taken for the whole period of trial. For the exhaust a continuous stream was sucked through a small pipe by a vacuum pump, the sample being taken at right angles to the floor of the main stream. The whole arrangement was devised by Mr. Huntley, and a very perfect average sample of gas and exhaust could thus be obtained.

Water.—The jacket water was run to waste over a syphon pipe, and was measured in calibrated tanks before it entered the jackets. The inlet and outlet temperatures were taken on standardised thermometers.

Counters.—Both revolutions and explosions were recorded by mechanical counters.

Power Developed.—The mean pressure from the nine diagrams is 60·3 lbs. per square inch, and the explosions being 84·7 per minute, the gross I.H.P. works out to 13·2. The mean pressure during the pumping stroke is 1·6 lb. per square inch, which should be subtracted from the 60·3 lbs. above to give the true effective mean pressure.

The net effective H.P. would then be 12·8.

With a net load of 126 lbs. and 172·1 revolutions per minute the brake H.P. = 11·47.

Mechanical Efficiency.—The mechanical efficiency will then be 89·6 per cent. reckoned on the net I.H.P., and 86·8 per cent. reckoned on the gross I.H.P.

Air used.—The air consumed was not directly measured, but its amount can be very closely calculated by the following

indirect method. The gas per explosion was ·0592 cubic foot, and the temperature of the meter being 51° Fahr. and the pressure of gas 14·75 lbs. per square inch, its specific volume would be $\frac{n \times (51 + 461)}{14{\cdot}75 \times 144}$. The value of n obtained from the analysis of the gas is 128·1, and the specific volume therefore would equal 30·95 cubic feet per lb. The weight of gas used per explosion is therefore $\frac{\cdot 0592}{30{\cdot}95} = \cdot 00191$ lb. On entering the cylinder this gas would be raised in temperature to a point which may be assumed to be midway between the outlet temperature of the jacket water and the meter temperature; here 60° to 89° Fahr., or 550° Fahr. above absolute zero.

The pressure at the end of the suction stroke measured upon the pumping cards is 13·1 lbs. per square inch. The specific volume of the gas on entering the cylinder is therefore $\frac{128{\cdot}1 \times 550}{13{\cdot}1 \times 144} = 37{\cdot}35$ cubic feet per lb., and the volume occupied by the gas $= \cdot 00191 \times 37{\cdot}35 = \cdot 07145$ cubic foot.

The total volume (cylinder + clearance) being ·8377 cubic foot, there remains ·8377 — ·07145 cubic foot to be occupied by air and exhaust products from the last explosion. The exhaust products will amount approximately to the volume of the clearance = ·2467 cubic foot, and their specific volume being (from the value of n obtained from the exhaust analysis, viz. 556) $\frac{556 \times 550}{13{\cdot}1 \times 144} = 16{\cdot}21$ cubic feet per lb.; their weight will be $\frac{\cdot 2467}{16{\cdot}21} = \cdot 01521$ lb.

The air will therefore occupy $\cdot 8377 - (\cdot 07145 + \cdot 2467) = \cdot 5196$ cubic foot. Its specific volume will be $\frac{53{\cdot}2 \times 550}{13{\cdot}1 \times 144} = 15{\cdot}51$ cubic feet per lb., and its weight, $\frac{\cdot 5196}{15{\cdot}51} = \cdot 03349$ lb.

The total weight of the charge will therefore be $(\cdot 00191 + \cdot 0152 + \cdot 03349) = \cdot 05061$ lb.

The ratio $\frac{\text{air and products}}{\text{gas}}$ by volume $= \frac{\cdot 76625}{\cdot 07145} = \frac{10{\cdot}72}{1}$

The ratio $\frac{\text{air and products}}{\text{gas}}$ by weight $= \frac{\cdot 04870}{\cdot 001913} = \frac{25\cdot 5}{1}$

Exclusive of products of exhaust $\Big\}$ $\frac{\text{air}}{\text{gas}}$ by volume $\frac{\cdot 5196}{\cdot 07145} = \frac{7\cdot 27}{1}$

" " by weight $\frac{\cdot 03349}{\cdot 001913} = \frac{17\cdot 5}{1}$

Temperatures (figs. 203 and 204).—The constants required for the calculation of the temperatures at the different points of the stroke will be as follows. From the analysis of the gas, its specific heat at constant volume (K_v) and at constant pressure (K_p) are (in foot lbs.)

$$\left.\begin{array}{l} K_v = 404\cdot 29 \\ K_p = 532\cdot 42 \end{array}\right\} K_p - K_v = N = 128\cdot 1$$

$$\text{Ratio } \frac{K_p}{K_v} = V = 1\cdot 316.$$

For the exhaust products after explosion the corresponding values are

$$\left.\begin{array}{l} K_p = 205\cdot 8 \\ K_v = 150\cdot 2 \end{array}\right\} \text{Difference } K_p - K_v = N = 55\cdot 6$$

$$\text{Ratio } \frac{K_p}{K_v} = V = 1\cdot 370.$$

For air the corresponding values are

$$\left.\begin{array}{l} K_p = 184\cdot 8 \\ K_v = 131\cdot 6 \end{array}\right\} \text{Difference } K \;\; - K_v = N = 53\cdot 2$$

$$\text{Ratio } \frac{K_p}{K_v} = V = 1\cdot 404.$$

For the mixture, air, gas, and exhaust products *before explosion*, in which 66·15 per cent. is air, 3·8 per cent. gas, and 30·05 per cent. exhaust products, by weight, the values should be—

$$K_p = \cdot 6615 \times 184\cdot 8 + \cdot 038 \times 532\cdot 4 + \cdot 3005 \times 205\cdot 8 = 203\cdot 9$$
$$K_v = \cdot 6615 \times 131\cdot 6 + \cdot 038 \times 404\cdot 3 + \cdot 3005 \times 150\cdot 2 = 147\cdot 5$$
$$\text{Difference } K \;\; - K_v = N = 56\cdot 4$$

$$\text{Ratio } \frac{K_p}{K_v} = V = 1\cdot 39.$$

As a check upon this last value N may be found from the known conditions of temperature, pressure, and volume at com-

mencement of the stroke, namely, $N = \dfrac{13{\cdot}1 \times 144 \times {\cdot}8377}{550 \times {\cdot}05061}$ $= 56{\cdot}7$.

The two values are here practically identical, showing that no serious error has been introduced by the above assumptions.

The expansion curve on the mean diagrams and the com-

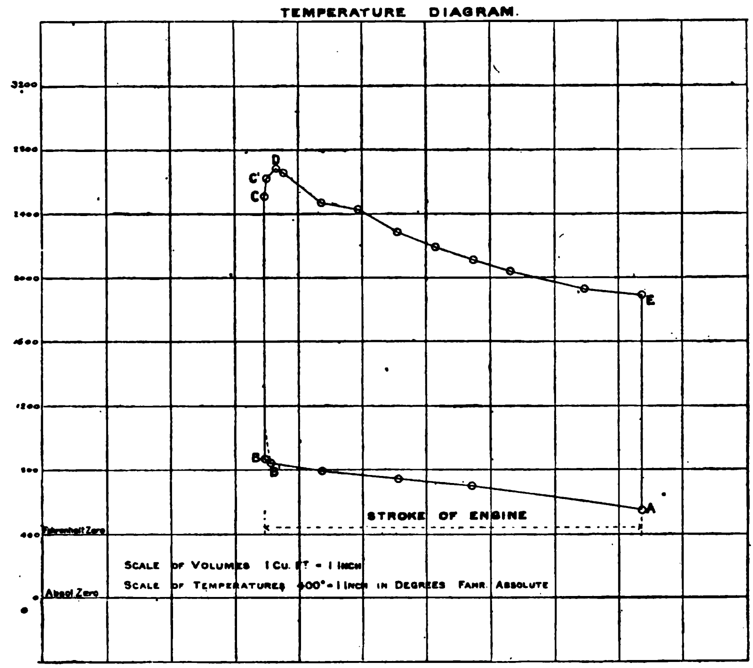


FIG. 203

pression curve may be expressed by an equation of the form $P\,V^n =$ a constant. For the expansion curve the value of 'N' is 1·31, and the compression 1·37. For adiabatic expansion the corresponding value would be 1·37, and for compression 1·39. The compression is therefore very nearly adiabatic, while during expansion a considerable amount of heat must have been added.

For the purposes of calculation the curves have been drawn with these indices and the theoretical card marked A B C D E assumed.

Its area is equivalent to 5,307 foot lbs., while the area of the actual mean card is equal to 5,140 foot lbs.

The temperature at A has, as already stated, been assumed

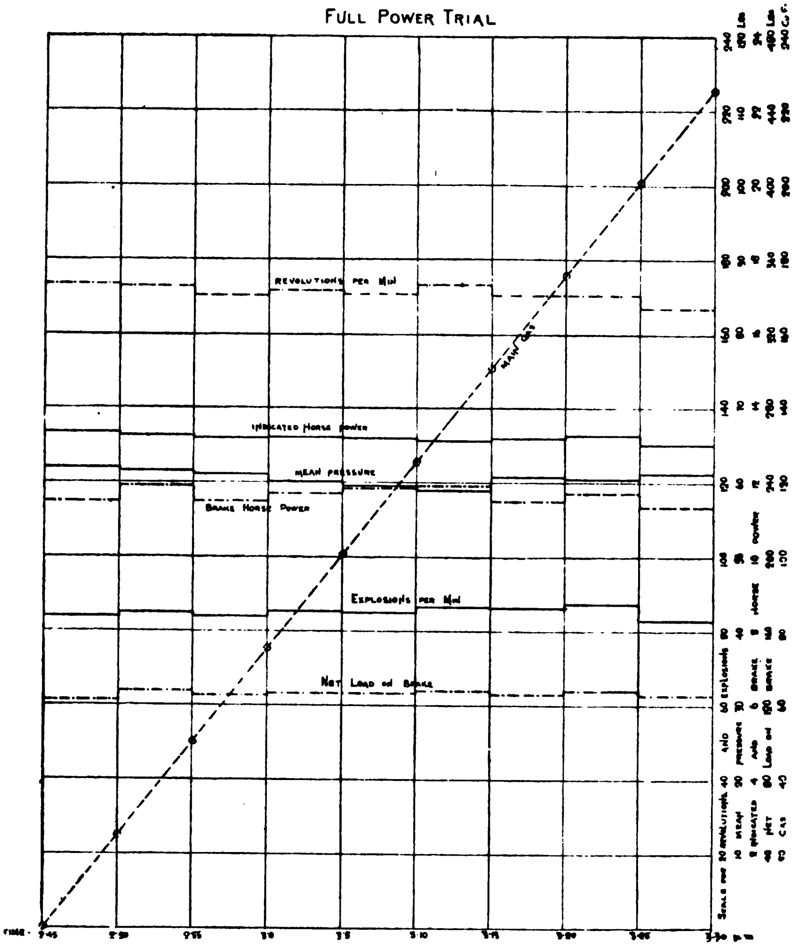


FIG. 204

equal to 550° above absolute zero Fahr. At B on the theoretical card the temperature will be—taking the value of N for this part of the cycle as 56·4 above, $\frac{69{\cdot}9 \times {\cdot}2467 \times 144}{56{\cdot}4 \times {\cdot}05061} = 869°$ abso-

lute ($69{\cdot}9 \times 144$ being the pressure per square foot, and $\frac{\cdot 2467}{\cdot 05061}$ the specific volume of the charge at B).

At C the pressure is $199 \times 144 =$ the specific volume $\frac{\cdot 2467}{\cdot 05061}$ and the value of N after explosion $55{\cdot}6$.

The temperature is, therefore, $\frac{199 \times 144 \times \cdot 2467}{55{\cdot}6 \times \cdot 05061} = 2510°$ absolute.

At D the pressure is 199×144, and the specific volume $\frac{\cdot 2641}{\cdot 05061}$; the temperature is therefore $\frac{199 \times 144 \times \cdot 2641}{55{\cdot}6 \times \cdot 05061} = 2690°$ absolute.

At E, the pressure being 44×144 pounds per square foot, and the specific volume $\frac{\cdot 8377}{\cdot 05061}$, the temperature is

$$\frac{44 \times 144 \times \cdot 8377}{55{\cdot}6 \times \cdot 05061} = 1885° \text{ absolute.}$$

The temperatures at a number of intermediate points have similarly been calculated, and the temperature diagram, fig. 203, plotted, in which the full line corresponds to temperatures calculated from the theoretical diagram, and the dotted line to the actual mean diagram.

Heat added.—From these temperatures the units of heat added at each part of the cycle may be found as follows:

During compression from A to B the mechanical equivalent of the heat added will be equal to the increase in the internal energy of the charge during the process, *i.e.* $K_v(T_2-T_1) \times$ weight of charge $= 147{\cdot}5(869-550){\cdot}05061 = 2{,}380$ foot lbs.

Similarly from B to C the heat added equals $150{\cdot}2(2{,}510-869){\cdot}05061 = 12{,}470$ foot lbs.

From C to $D = K_p(T_2-T_1) \times$ weight of charge $= 205{\cdot}8(2{,}690-2{,}510){\cdot}05061 = 1{,}845$ foot lbs.

During expansion the heat added will be equal to the difference between the work done and the loss of internal energy from D to E. The work done will equal $\frac{p_1v_1-p_1v_2}{n-1} \times$ weight

of charge$=\frac{(199\times\cdot2641-44\times\cdot8377)144}{\cdot31}$, ·2641 and ·8377 being equal to the total volume occupied by the charge at D and E respectively: that is, the specific volume v_1 and v_2 multiplied by ·05167, the weight of the charge. This equals 7,290 foot lbs.

The loss of internal energy from D to E will equal $K_v(T_1-T_2)\times$ weight of charge$=150\cdot2(2{,}690-1{,}885)\times\cdot05061$ $=6{,}105$ foot lbs.

During the expansion, therefore, $7{,}290-6{,}105=1{,}185$ foot lbs. must have been added.

The total heat accounted for by the diagram is, therefore, $2{,}380+12{,}470+1{,}845+1{,}185=17{,}880$ foot lbs.

Exhaust.—If from this sum we subtract the total amount of work done during the cycle, the remainder will equal the heat rejected in the exhaust. The work done during constant pressure expansion C to D equals $p_1(v_2-v_1)=44\times199\times(\cdot2641-\cdot2467)=499$ foot lbs.

The work done during expansion from D to E is, as above, 7,292 foot lbs. The total work is, therefore, $7{,}290+499=7{,}789$ foot lbs. Subtracting this from 17,880 foot lbs. above, the remainder $(17{,}880-7{,}789)=10{,}096$ foot lbs. will represent the heat rejected in the exhaust.

This may be checked by direct calculation from the known temperatures at E and A, for the loss of internal energy in completing the cycle from E to A will evidently be the amount of heat rejected in exhaust. This will equal $K_v(T_1-T_2)\times$ weight of charge$=150\cdot2(1{,}885-550)\cdot05061=10{,}140$ foot lbs., which corresponds with the quantity found indirectly above well within the limits of accuracy possible in measurements of this kind.

Heat rejected in jackets.—The jacket water used per explosion being ·18 lb. and the rise in temperature 89·2° Fahr., the mechanical equivalent of the heat rejected (taking the mechanical equivalent of one B.T.U. at 778 ft. lbs.) will equal $\cdot18\times89, 2\times778=12{,}400$ ft. lbs.

Thermal Equivalent of Gas.—The gas analysis gives as the thermal equivalent of the gas used on trial 18·900 B.T.U per pound.

Heat Account.—A heat account can therefore be constructed, and would stand thus :—

Heat expended (by analysis) per explosion = ·00191 lb. of gas × 18·900 × 778 = 28,100 ft. lbs.

Heat Accounted for by Diagrams.—(B to C)12,470 + (C to D) 1,845 + (D to E) 1,185 + (heat rejected in jackets)12,400 = 27,900.

Heat Accounted for on trial :—

Mechanical equivalent of indicator diagrams	5,140
Heat rejected in jacket water	12,400
Heat rejected in exhaust	10,140
Total	27,680

TABLE I

Particulars of Engine

1.	Diameter of cylinder, in inches	8·5
2.	Stroke, in inches	18
3.	Diameter of flywheel, in feet	5·5
4.	Effective circumference of flywheel, in feet	17·458
5.	Duration of trial, in minutes	40

Indicated Horse-power

6.	Cylinder constant, per lb., mean pressure, per explosion	·002579
7.	Number of indicator diagrams taken	9
8.	Average mean pressure during working stroke, in lbs.	60·3
9.	Average mean pressure during pumping stroke, in lbs.	1·6
10.	Nett average pressure	58·7
11.	Total explosions	3387
12.	Explosions per minute	84·7
13.	I.H.P., gross, from lines 6, 8, and 12	13·2
14.	I.H.P., nett, from lines 6, 10, and 12	12·8

Brake Horse-power

15.	Wheel, constant, per lb. per revolution	·000529
16.	Load on brake, gross lbs.	202
17.	Load on spring balance, mean lbs.	76
18.	Load, nett average, in lbs	126
19.	Total revolutions	6,884
20.	Revolutions per minute	172·1
21.	Brake horse-power lines 15, 18, and 20	11·47

Gas Consumption

22.	Gas total, in cubic feet (without ignition)	201
23.	Gas per explosion	·0593
24.	Gas ignition, total, in cubic feet	5·8
25.	Pressure of gas at meter, in inches of water	1·85
26.	Pressure, in lbs. per sq. inch	14·68
27.	Temperature of gas at meter, Fahr.	51°
28.	Specific volume of gas, in cubic feet per lb.	30·95
29.	Gas used per explosion (without ignition), in lbs.	·00191
30.	„ „ I.H.P. per hour (without ignition), in cubic feet	22·8
31.	„ „ „ „ (including ignition), in cubic feet	23·5
32.	„ „ B.H.P. „ (without ignition)	26·2
33.	„ „ „ „ (including ignition)	27

TABLE II

Temperatures

		Above absolute zero	Above Fahr. zero
1.	Assumed temperature of charge at end of suction stroke, in degrees Fahr.	550°	89°
2.	Temperature of charge at end of compression B on theoretical card	869°	408°
3.	Temperature on completion of constant volume addition of heat at C	2,510°	2,049°
4.	Temperature on completion of constant pressure expansion at D	2,690°	2,229°
5.	Temperature at exhaust E	1,885°	1,424°

TABLE III

Data for Heat Account

1.	Gas consumed per explosion, in lbs. (Table 1, line 29)	·00191
	Calorific value of ditto at 18,900 B.T.U. per lb. (Table line)	36·1 B.T.U
3.	Mechanical equivalent of ditto, in ft. lbs.	28·100
4.	Work done by charge, calculated, gross (page 7)	7,789 ft. lbs.
5.	Work done on charge during compression (calculated)	2,484 „
6.	Nett work in ideal process, A, B, C, D, E	5,307 „
7.	Nett work, mean, of all indicator diagrams	5,140 „

Heat taken up

8.	Heat taken up by charge during compression (A to B)	2,380 ft. lbs.
9.	„ „ „ at constant volume (B to C)	12,470 „
10.	„ „ „ at constant pressure (C to D)	1,845 „

11.	Total heat turned into work during expansion above zero pressure (page 6)	7,289	lbs.
12.	Loss of internal energy during expansion (page 7)	6,105	„
13.	Difference (11—12) = heat added during expansion	1,184	„
14.	Total heat added during cycle lines 8, 9, 10, and 13	17,880	„
15.	Total work done above zero pressure (line 4)	7,789	„
16.	Difference (14—15) = heat rejected in exhaust	10,096	„
17.	Heat rejected in exhaust, direct calculation (page 240)	10,140	„

Jacket Water

18.	Jacket water used per explosion, in lbs.	0·18
19.	In-going temperature of jacket water, Fahr.	41·8°
20.	Out-going „ „ „	131°
21.	Rise of „ „ „	89·2°
22.	Mechanical equivalent of heat rejected in jacket water per explosion, in ft. lbs.	12·400

TABLE IV

Efficiencies

1. Mechanical efficiency $\frac{\text{B.H.P.}}{\text{I.H.P.}}\left(\text{Table I}\ \frac{\text{line 21}}{\text{line 13}}\right)$ . . . ·869

2. Mechanical efficiency $\frac{\text{Line 21}}{\text{Line 14}}$ Table I. . . . . ·896

TABLE V

Heat Account

Dr.	Ft. lbs.
Total heat of combustion of ·00191 lb. gas per explosion at 18,900 B.T.U. per lb. = ·00191 × 18,900 × 778	28,100

Cr.	Ft. lbs.	Per cent.
Work done.		
Effective work (B.H.P.) per explosion	4,467	15·9
Do. lost in friction	673	2·4
Shown on diagrams, I.H.P.	5,140	18·3
Heat rejected.		
Jacket water	12,400	44·1
Exhaust	10,140	36·1
Radiation and otherwise unaccounted for	420	1·5
	28·100	100·0

Heat accounted for on diagram.	
Heat supplied.	Ft. lbs.
From B to C	12,470
„ C to D	1,845
„ D to E	1,184
	15,499
Rejected.	
Jacket water	12,400
Lost by radiation, &c.	201
	28,100

TABLE VI.—*Chemical Analysis*

COAL GAS

Symbols and Name	Proportion by Volume	Weight per cubic foot	Weight of, in one cubic foot of Coal Gas	Proportion by Weight	Specific Heat (constant Volume)	B.T.U.s to raise Weight found in 1 lb. of Coal gas 1° F.	Specific Heat (constant Pressure)	B.T.U.s Units to raise Weight in 1 lb. of Coal Gas 1° F.	Calorific value of, per pound	B.T.U.s evolved by perfect combustion of Weight found in 1 lb. of Coal Gas
		lbs.	lbs.		B.T.U.s					
CO_2 Carbonic Acid .	0·6	·123	·000738	·0218	·172	·003756	·2169	·004728	—	—
C_2H_4 / C_4H_8 } Olefines .	5·3	·1174	·006221	·1841	·359	·06609	·4040	·07438	21,200	3,900
									Taken as half C_2H_4 and half C_4H_8	
O_2 Oxygen . .	0·3	·0895	·000268	·0079	·1551	·001225	·2175	·001725	—	—
CO Carbonic Oxide .	8·6	·0783	·006733	·1992	·1736	·03458	·2450	·04881	4,300	463
CH_4 Methane . .	33·7	·0447	·015063	·4457	·468	·2086	·5929	·2642	23,200	10,340
H_2 Hydrogen . .	48·9	·00559	·002733	·0809	2·411	·1950	3·4093	·2758	52,500	4,247
N_2 Nitrogen . .	2·6	·0783	·002036	·0604	·1727	·0104	·2438	·0147	—	—

Cv. = ·5196 B.T.U.s Cp. = ·6844 Cal. value = 18950 B.T.U.s

Specific heat of Coal Gas at constant pressure = Cp. = ·6844 B.T.U.
Specific heat of Coal Gas at constant volume = Cv. = ·5196 B.T.U.

$$\cdot6844 \times 778 = Kp = 532\cdot4 \text{ ft. lbs.}$$
$$\cdot5196 \times 778 = Kv = 404\cdot3 \text{ ft. lbs.}$$
$$Kp - Kv = n = 128\cdot1$$
$$\frac{Kp}{Kv} = V = 1\cdot316$$

EXHAUST PRODUCTS

Symbols and Name	Proportion by Volume	Weight per cubic foot	Weight of, in one cubic foot	Proportion by Weight	Specific Heat (constant Volume)	B.T.U.s to raise Weight 1° F.	Specific Heat (constant Pressure)	B.T.U.s Units to raise Weight 1° F.	Calorific value of, per pound	B.T.U.s evolved by perfect combustion
CO_2 Carbonic Acid .	8·59	·123	·01267	·136	·172	·0234	·2169	·0295	—	—
O_2 Oxygen . .	2·58	·0895	·00277	·030	·1551	·0046	·2175	·0065	—	—
N_2 Nitrogen . .	72·23	·0783	·0678	·727	·1727	·1255	·2438	·1772	—	—
H_2O Steam . .	16·58	·0503	·0100	·107	·370	·0396	·480	·0514	—	—

Cv = ·1931 Cp = ·2646

$$Cp \times 778 = \cdot2646 \times 778 = Kp = 205\cdot8$$
$$Cv \times 778 = \cdot1931 \times 778 = Kv = 150\cdot2$$
$$Kp - Kv = n = 55\cdot6$$
$$\frac{Kp}{Kv} = V = 1\cdot370$$

Specific heat at constant pressure = Cp = ·2646 B.T.U.
Specific heat at constant volume = Cv = ·1931 B.T.U.

THE 'FORWARD.' GAS ENGINE

Consumption and Temperature Trials

The 'Forward' Otto gas engine, which 'The Engineer,' April 6, 1894, illustrates on page 293, built by Messrs. T. B. Barker & Co., of Birmingham, has recently undergone a series of brake and indicator tests, the results of which are given in the annexed table. These trials were made at the instance of the city of Birmingham gas department—to whom the engine was supplied—and conducted by Mr. Morrison, the assistant engineer of the Saltley Gas Works, in conjunction with Mr. F. W. Lanchester.

This engine works on the now almost universally adopted Otto cycle, with independent feed and exhaust valves and gas valve actuated by hit-and-miss mechanism controlled by a centrifugal governor. The ignition is effected by a tube igniter without a timing valve of any description. A glance at results of these trials and the indicator cards taken will show how superfluous such an adjunct appears to be. The makers consider that an ignition valve adds to the complexity of an engine without compensating advantages. This engine is of 30 maximum brake horse-power, and has a cylinder 12 inch diameter by 20 inch stroke. The crank shaft is of forged Siemens-Martin steel, 4$\frac{3}{8}$ diameter at journals. The brasses are phosphor bronze throughout, and ample bearing surfaces are allowed, the mean pressures during the working stroke being as follows: Piston pin, 535 lbs. per square inch; crank pin, 375 lbs. per square inch; main bearings, 100 lbs. per square inch. The piston packing consists of four cast iron rings $\frac{5}{8}$ inch wide, fitted between junk rings in the usual manner, each ring having a baffle groove turned in its surface $\frac{1}{8}$ inch wide, dividing the bearing surface of the ring into two bands $\frac{1}{4}$ inch wide; the pressure exerted by the ring on the walls of the cylinder liner amounts to 5 lbs. per square inch of surface.

This engine is fitted with a Lanchester multiple impulse self-starter, of which we gave a description in Volume lxxii., No.

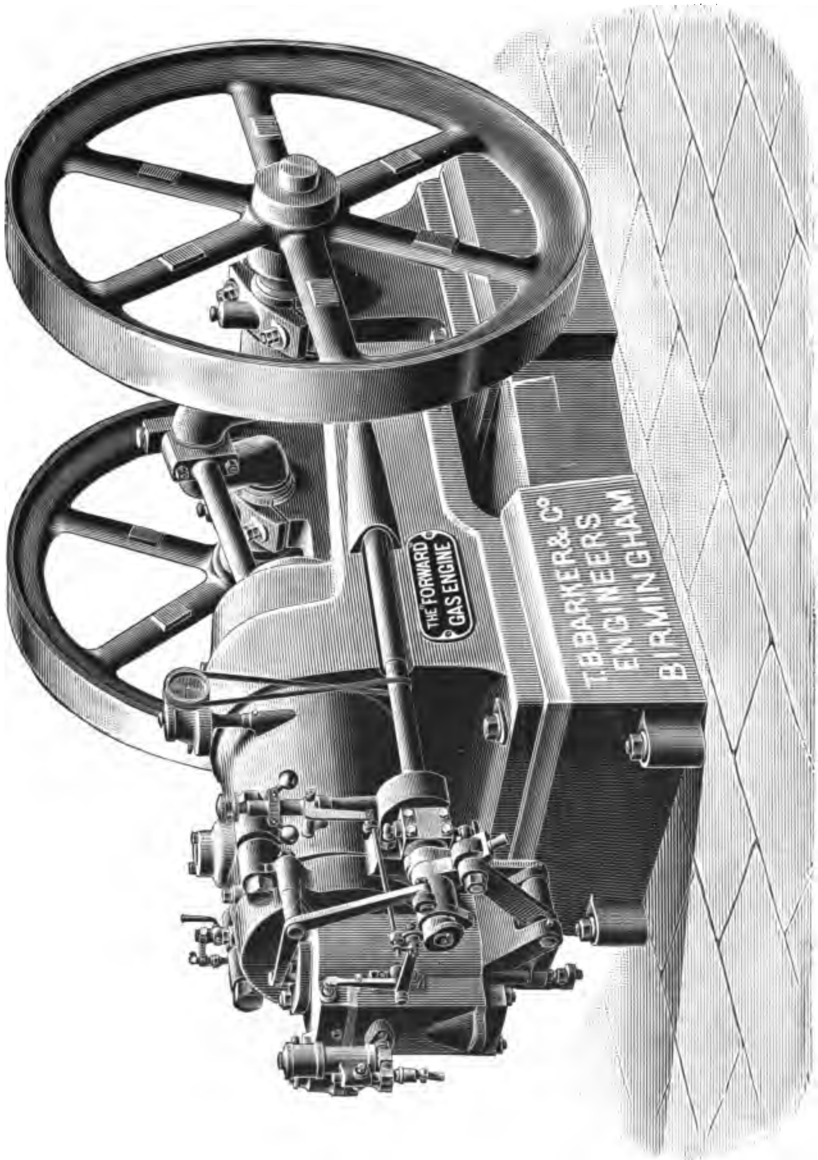


FIG. 205.—30 B.H.P. 'FORWARD' ENGINE

1860. This starter is arranged not only to give the initial impulse necessary to set the engine in motion, but gives a series of low-pressure impulses at the commencement of the working strokes until sufficient speed is acquired to overcome the compression. In fig. 1, plate 206, line *a* shows the expansion curve of initial explosion, lines *b b b* show subsequent series of low-pressure explosions, ignition being effected in all cases by the starting igniter; the tube igniter only comes into operation when the exhaust roller is thrown off relief cam.

Referring to the tabulated results of the trials, it will be seen that a gas consumption as low as 21 feet per brake horse-power hour has been obtained. This, we are informed, is 1 foot less than the makers guarantee, and is one of the best results ever recorded to our knowledge. The gas consumption per indicated horse-power hour ranges from 16¾ feet to 17¾ feet. We are not aware that as low figures as these have been previously obtained with an engine of this size. The calorific value of the gas is taken as 576,730 foot-pounds per cubic foot at 14·7 lbs. pressure and O.C.; this is the value calculated by Mr. Dugald Clerk from the analysis of Dr. P. Frankland of 17¼ candle-power Birmingham gas. This, in the absence of anything more recent, may be taken as approximately correct. Corrections are made for temperature and pressure.

With the object of determining the composition of the charge and its temperatures at various points of the cycle, some further experiments were afterwards carried out by Mr. F. W. Lanchester at Messrs. Barker's works. These experiments were directed to determine, firstly, the temperature of the charge entering the cylinder before admixture with the residuals; secondly, the temperature of the residuals themselves. The temperature of the charge was recorded by a thermometer placed in a hole specially drilled in the feed valve box so as to project to within 1½ inch of the valve, the bulb of the thermometer being protected from radiation by a cylindrical paper screen; the actual readings with the engine at nearly full load ranged up to 44° C. The further increase of temperature which would take place in passing the valve and port would in all probability bring this up to 50° C., which, for purposes of calcula-

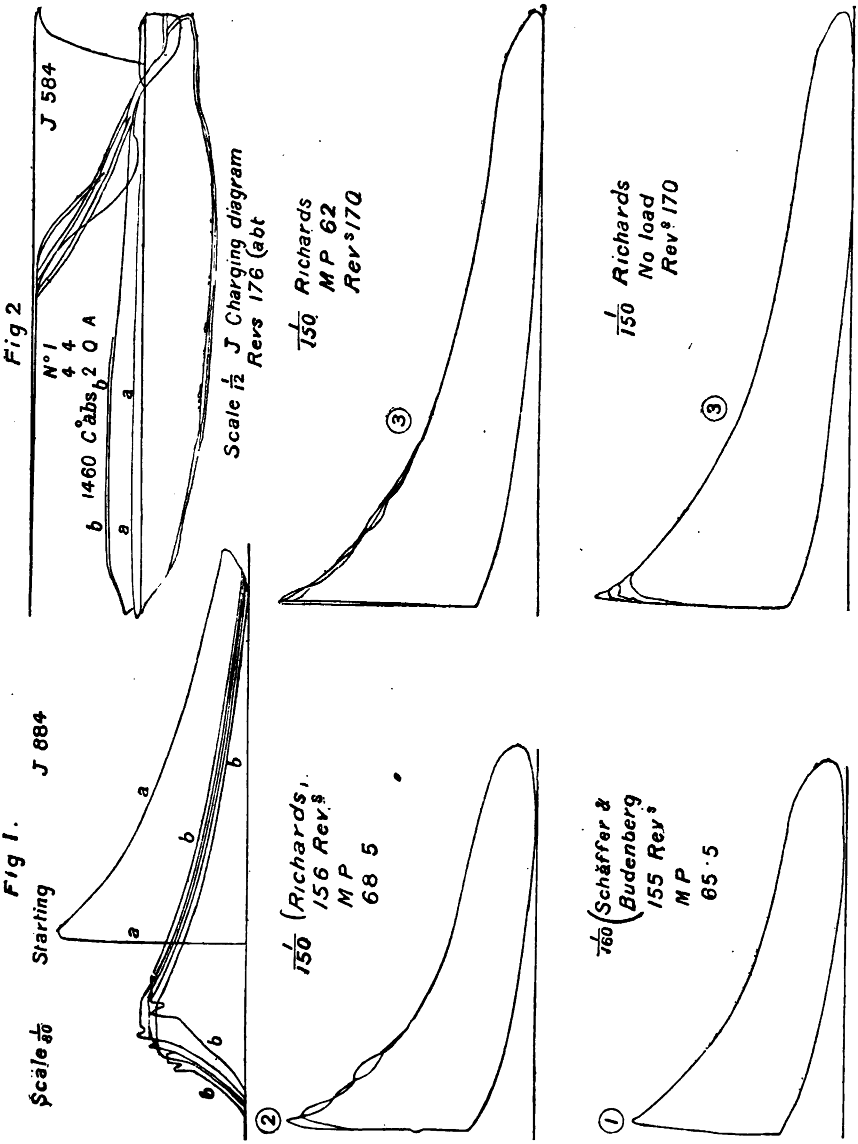


FIG. 206.—INDICATOR DIAGRAMS FROM FORWARD ENGINE

tion, is taken to be the temperature. The temperature of the residual exhaust gases cannot easily be determined directly with any degree of accuracy. The methods used by Professor Thurston and Dr. Slaby will hardly bear criticism; it may be useful to know in an engine of a certain size that a pot of zinc placed with due precautions in the exhaust pipe will melt, whereas a pot of antimony will not; but this has only a remote connection with the temperature of the residuals remaining in the compression space.

In order to determine the temperature of the exhaust gases during the return stroke in these experiments the exhaust pipe was entirely removed, and diagrams were taken with a carefully adjusted indicator to a scale of 1 lb. $= \frac{1}{12}$ inch, showing the exhaust back pressure both with full load and running light, precautions being taken to insure constancy of speed. Fig. 2 shows one of the diagrams so obtained, in which a is the exhausting curve at full load, and b is the curve obtained when running light. The greatest back pressure observed is about 2 lb. above the atmosphere, consequently we may assume that the density of the gases is proportional to their back pressure without making any serious error. Now the temperature of the no load gases—air—is known to be about 50° C. = 323° absolute, then the temperature of the exhaust gases absolute will be $\frac{323\,b}{a}$ the temperature varying inversely as the density. Taking the mean of four diagrams, we get 1432° absolute = 1159° C. This cannot be far from the truth, and it is about what would be expected when it is considered that the expansion curve towards the end of the working stroke becomes practically isothermal, which means that heat is being supplied by after combustion more rapidly than it is being lost through the cylinder walls; it seems improbable, therefore, that the temperature would fall very substantially during the discharging stroke.

The actual volume of the charge at atmospheric pressure is somewhat less than the total contents of the cylinder, and is given by the point of intersection of the compression curve and atmospheric line on the charging diagram—see fig. 2. The volume of residuals remaining in the cylinder is slightly greater

than that of the compression space. Taking the volume of charge at atmospheric pressure as 100 units, then that of compression space = 32·6 and volume of residues unexpelled = 33·3. Now the volume of the whole of the charge at atmospheric pressure and exhaust temperature would equal $\frac{50 \text{ by } 100}{14 \cdot 7} =$ 340, or the proportion of residuals in the charge $= \frac{33 \cdot 3}{340} = 9\frac{3}{4}$ per cent. The composition of the charge at full load and no load is given on tables I. and II.

Fig. 207 shows the temperature of the various points of the cycle plotted as curves, the full load curve showing a higher temperature at all points of the cycle, owing to the initial admixture of the hot residues to the charge. The dotted line C is the temperature curve for a true adiabatic, and the position of the actual curve above or below this shows the balance or deficit of heat due to after combustion and loss through the cylinder walls; during the first part of the stroke the latter predominating, and *vice versâ*. These curves are calculated on the assumption that the mixture behaves as a perfect gas both before and after ignition, and that no change of mean molecular weight takes place during combustion. Some measurable inaccuracy is thus doubtless introduced, but it is usual to make these assumptions to avoid complex calculations. Table III. gives the temperature at the various points in the cycle.

The theoretical efficiency of an Otto engine of these proportions is 36 per cent., the difference between this and the 24 per cent. actually obtained being mostly due to the loss of heat through the water jacket. Table V. shows the distribution of energy utilised and lost.

TABLE I

Composition of Charge

No Load	Cub. in.	Per cent.
Gas	203·3	6·42
Air	2962·7	93·58
		100·00

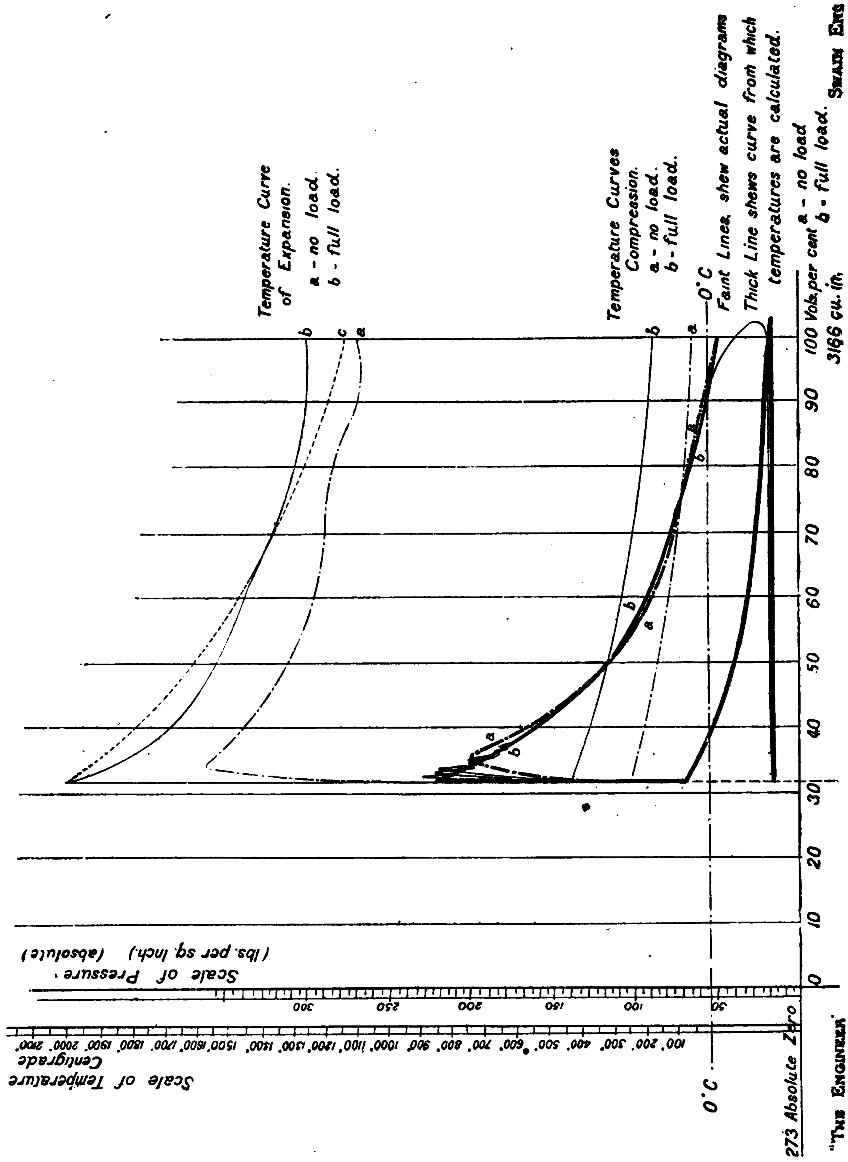


FIG. 207. INDICATOR DIAGRAMS AND ESTIMATE TEMPERATURES

TABLE II

Composition of Charge

Full load	Cub. in.			Cub. in.	Per cent.
Gas . . .	203·3			203·3	8·58 Gas.
Air for combustion of above gas	1236·0				
Excess of air .	659·7			2006·95	84·84 Total air.
Residues from previous charge $9\frac{3}{4}$ per cent.	231·0 consisting of	Air . .	75·25		
		Products of combustn. &c	155·75	155·75	6·58 Prod. of combustion, &c.
					100·00

TABLE III

Temperatures

	No load	Full load
Initial	50 deg. C.	175 deg. C.
Compression . . .	233 ,,	429 ,,
Maximum explosion . .	1348 ,,	1962 ,,
Exhaust maximum . .	865 ,,	1253 ,,
Exhausting stroke . .	— ,,	115 ,,

TABLE IV

Summary of Brake and Indicator Tests at City of Birmingham Corporation Gasworks, Saltley

Brake circumference 17 ft. exactly.
Cylinder diameter 12 in., stroke $19\frac{7}{8}$ in.

	December 22.		January 8.	
	1	2	3	4
Duration of test	½ hour	¾ hour	¼ hour	1h. 2m.
Mean revolutions per minute . .	154·7	156	207·25	170
Mean nett load	232·5	248	278·75	261·3
Brake horse-power	18·5	19·9	29·8	22·95
Mean explosions per minute . .	64·3	64	96·1	79·1
Mean pressure of cards	67	67	67	60·3
Indicated horse-power	24·4	24·3	36·6	27·15
Mechanical efficiency	·76	·82	·814	·84
Gas consumed, in cubic foot per hour (ignition excluded)	405·5	409·5	648·75	481·25
Gas per B.H.P. hour (ignition excluded)	21·9	20·6	21·3	21·05
Gas per I.H.P. hour (ignition excluded)	16·6	16·85	17·7	17·75

	December 22.		January 8.	
	1	2	3	4
Duration of test	½ hour	¾ hour	¼ hour	1h. 2m.
Gas for ignition, cubic feet per hour.	6	6	5¼	5¼
Candle power of gas	17·26	17·26	17·20	17·20
Gas, cubic feet per explosion	·105	·107	·1125	·102
Foot-pounds indicated per explosion	12,533	12,533	12,133	11,280
Foot-pounds indicated per cubic foot of gas	119,400	117,100	111,300	110,700
Calorific value of gas in foot-pounds per cubic foot corrected for temperature and pressure	485,000	485,000	498,000	498,000
Total efficiency (indicated)	·256	·242	·223	·222
Total efficiency, brake	·187	·198	·183	·186

TABLE V

Energy Utilised and Lost

	Per cent.
Indicated as work in motor cylinder	24
Lost as heat through water jacket—*less than*	33
Lost as heat in exhaust gases—*greater than*	43
Total	100

The above results, obtained without any attempt at 'scavenging,' are exceedingly good.

To measure the temperature of the exhaust gases, the composition of the charge, the indicator introduced by Mr. Lanchester is a new departure.

CHAPTER XXXVII

PRIVATE ELECTRIC LIGHTING

WITHIN the past few years electricity has forced its way very rapidly and become almost general for lighting purposes. The dynamo is the machine used to generate electricity; and amongst the various forms of prime movers the gas engine is taking an important place after the steam engine.

Circumstances invariably decide which of the various forms of gas engine is the best to adopt; but as at times the question of comparative cost of production and distribution, both initial and continuous, has to be taken into consideration, the author

thinks the information contained in the appended series of tests (whilst not altogether within the scope of this treatise), taken to arrive at the working cost of two or three private installations, by Mr. Thomas Hanning, A.M.I.C.E. (who has made a special study of this subject, and who has given the author the results of his valuable experience), may be of considerable use.

In towns supplied by electric energy from central stations the question to be considered is whether it would be more economical for the consumer to lay down a private generating plant or take his current from the town supply. The prices charged by electric lighting companies vary from $4\frac{1}{2}d.$ to $8d.$ per Board of Trade unit, or 1,000 Watts hours; whereas it will be found, from the annexed tables, that current can be privately generated at something under $1d.$ per unit—that is, for fuel consumption alone. It should, however, be mentioned that all these cases may be termed favourable for private generating, since they represent long working hours—a most important point in comparing public lighting with private installations.

In the first test, for instance, the plant works all the hours of darkness in the year, with the exception of Sundays, and practically has as large a load as possible under ordinary conditions. Even 1,000 hours' lighting a year is equivalent to an average of about four hours per day for the nine months when artificial illumination may be necessary. In engineering shops the annual period during which artificial light is used is not more than 300 hours unless overtime is worked.

The fuel consumption is greatly increased with varying loads, because of (1) the waste in getting up steam and keeping boilers banked up; (2) the decrease in mechanical and thermal efficiency of the steam engine with light loads. The steam consumption per horse-power increases as the average load factor decreases.

It may also be seen that with gas engines, although the cost per unit generated remains fairly constant, the lighter load factor greatly increases the total average cost per unit, the amount set aside for interest on first cost and depreciation being a fixed charge.

The following are the results and conclusions arrived at by Mr. Hanning in his report:—

It will be interesting to consider the facts arising out of these tests in rotation as they appear in the tabulated list.

Consumption of Gas.—In relation to the lamps burning, the consumption is lower in No. 3 test than in No. 2, due probably to the fact that the engine is more nearly proportioned to the work it has to do.

Cubic feet of gas consumed per I.H.P.—A remarkable and noticeable feature in the perusal of these figures is that in the whole of the tests the gas consumption—in relation to the I.H.P.—is lower at a certain light load than at full load. This must be in some way due to the regulation of the gas valve, which at these loads was not full open, but shut off to a certain extent.

In No. 4 test (Olympia) the engine was fired electrically; therefore there was no gas consumed for firing, as in the other cases.

Indicated Horse-power.—There is a striking similarity in the figures of power required to do the full load in steam engines and gas engine plants Nos. 1 and 2 tests, which will no doubt surprise many who contend that the steam engine is more efficient than the gas engine. A comparison of the power required to generate energy for a certain number of lamps by a large engine and small is shown on tests Nos. 2 and 3, or in No. 2. 40 I.H.P. is required for 200 16 C.P. lamps, and 48 for 300; whereas in No. 3 30 I.H.P. suffices for 220 lamps, and 39 I.H.P. for 300.

Number of lamps burning per I.H.P.—There is a great regularity about these figures which should almost make them standards for the purpose of calculation.

Consumption of gas in cubic feet per lamp hour.—The same may be said of this.

Reading on switch-board in volts.—It would appear as though the machines in Nos. 1 and 4 tests were over-compounded.

Reading in ampères.—In No. 1 test 112 ampères is required

PARTICULARS OF TESTS OF PRIVATE ELECTRIC LIGHTING INSTALLATIONS

Taken by Mr. Thomas Hanning, A.M.I.C.E. Newcastle-on-Tyne

Lamps: Number of Lamps Lit	Engine: Coal consumption in pounds per Indicated H.P. / Consumption of Gas in cubic feet per hour	Engine: Waterconsumption in pounds per Indicated H.P. / Cubic feet of gas consumed per Indicated H.P.	Engine: Indicated Horse-power worked out from Diagrams / Indicated H.P. worked out from Diagrams	Engine: Number of Lamps burning per Indicated H.P. / Number of Lamps burning per I.H.P.	Engine: — / Consumption of Gas in cubic feet per Lamp hour	Dynamo: Reading on switch-board in Volts	Dynamo: Reading on switch-board in Ampères	Dynamo: Watts consumed for each Lamp	Dynamo: Total output of Dynamo in Kilowatts	Dynamo: Electrical output in Horse-power	Combined efficiency between H.P. of Engines and output of Dynamo	Cost of Coal and water per unit of Electricity generated / Cost of Gas per unit of electricity generated	Estimated Lamp hours per annum	Estimated Electrical units used per annum	Rate per unit due to Interest, Depreciation, and Attendance, &c.	Total average cost per unit	Total average cost per Lamp hour	Average number of Lamps lit per hour for 1d.	Estimated total cost per annum for Installation	Consumption of Gas per Kilowatt hour	Average consumption of gas per Kilowatt hour
I. *Steam Engine Plant (exclusive of Boiler).*—Installed in 1891																					
											Per cent	d			a	d	d		£ s. d.		
200	—	—	37·5	5·33	—	102	112	57·12	11·42	15·3	40·8	·40	1,050,000	63,000 at 60 Watts per Lamp hour	1d	1·4	·084	11·9	367 10 0		
400	5	35	53	7·54	—	103	240	61·8	24·72	33·1	52·5										
II. *'Crossley' Gas Engine Plant.*—Cylinder, 16 inches diameter; stroke of engine, 21 inches; revs. per minute, 160. (Installed in 1893.)																					
200	740	18·5	40	5	3·70	107	125	66·6	13·375	18	45	1·095								55·3	
300	840	17·5	48	6·25	2·80	107	173	61·7	18·511	24·8	51	·90	250,000	16,000 at 64 Watts per Lamp hour	2·8	3¾	·234	4·266	250 0 0	44·3	48
400	1130	20·9	54	7·4	2·825	106	240	63·6	25·44	34	63	·88								44·4	
III. *'Tangye' Gas Engine Plant.*—Cylinder, 13 inches diameter; stroke of engine, 20; revs. per minute, 160. (Installed in 1893.)																					
100	320	18·82	17	5·88	3·20	105	60	63·00	6·30	8·44	50	·99								50·7	
220	640	21·33	30	7·3	2·90	105	135	64·43	14·17	19·00	63·3	·89	225,000	14,175 at 63 Watts per Lamp hour	3	3·9	·244	4·10	230 6 10½	45·1	45·9
300	770	19·75	39	7	2·56	102	180	61·20	18·36	24·61	63·1	·83								41·9	

TEST OF PRIVATE ELECTRIC LIGHTING PLANT AT 'OLYMPIA,' NEWCASTLE-ON-TYNE

Taken by Mr. Thomas Hanning, A.M.I.C.E., for the Directors of 'Olympia,' Limited, March 28, 29, and 30, 1895

'*Clarke-Chapman' Gas Engine Plant.*—Cylinder, $13\frac{1}{4}$ inches diameter; stroke of engine, 22 inches

ENGINE							DYNAMO										
Indicated Horse-Power	Brake Horse-Power	Cubic Feet of Gas used per hour	Cubic Feet of Gas used per I.H.P.	Cubic Feet of Gas used per B.H.P.	Speed in Revs. per Minute	Efficiency $\frac{\text{B.H.P.}}{\text{I.H.P.}}$	Volts at Terminals	Ampère Readings at Switch-board	Speed in Revs. per Minute	Total Kilo-watts	Gas consumed per Kilo-watt hour	Electrical Horse Power	Electrical Efficiency	Combined Efficiency $\frac{\text{E.H.P.}}{\text{I.H.P.}}$	Cost of Gas per Hour	Cost of Gas per Kilo-watt Generated	Load
						Per cent.					Cubic ft.		Per cent.	Per cent.	Pence	Pence	
9	—	267	29·6	—	160	—	105	—	1165	—	—	—	—	—	5·34	—	Dynamo-excited light
18·5	12	380	20·5	31·6	158	65	106	65	1135	6·89	55·1	9·23	—	50	7·6	1·10	$\frac{1}{3}$
25	19	560	22·4	29·5	156	76	106	100	1105	10·6	52·8	14·21	—	56·84	11·2	1·06	$\frac{2}{3}$
31	25	660	21·3	26·4	154	80	105	152	1110	15·96	41·3	21·39	92	69	13·2	·825	Full
38	32	770	20·26	24·0	156	84	—	—	—	—	—	—	—	—	—	—	Brake

Watts per I.H.P. full load = 514·84. Watts per B.H.P. full load = 638·4.

Gas at 1*s.* 8*d.* per 1,000 cubic feet.

for 200 lamps, and 125 in No. 2. This is no doubt due to a difference in the resistance of the lamps and wiring.

Watts consumed per lamp.—The fluctuation in these figures is difficult to account for, and point to probable unintentional switching on and off of the lamps by the workpeople.

Output of Dynamo in kilowatts.—The higher output in Nos. 2 and 3 tests is due to the higher voltage to which the machines are run to overcome loss over large area of circuits.

Electrical output in H.P.—In proportion to the number of lamps burning this is fairly consistent throughout.

Combined efficiency.—These figures are important to all concerned in electrical engineering, as they give results from actual every-day practice, and are not derived from specially prepared plant, which is the case in a great many of the tests which have up to the present been published.

The steam engine plant is slightly more efficient than gas engine plants Nos. 2 and 3, but No. 4 stands highest—due in a great measure to the higher efficiency of this dynamo.

Cost of Fuel, &c.—From the results it would appear that with a steam driver plant the cost of water and coal is about half the cost of gas (at 1*s*. 7·8*d*. per 1,000 cubic feet) consumed by a gas engine, and that the total cost of generating a unit of electricity is about 20 per cent. less in favour of the former (see notes as to rates of interest, &c.). But against this is to be put the increase in rate which would be chargeable to the steam plant due to interest and depreciation on boiler, repairs to same, &c., cost of stoking and carting away clinkers, ashes, &c., which has not been estimated for. The cost of gas is noticeably constant in these tests.

Number of lamp hours.—This is one of the most important factors to be considered in comparing the cost of lighting as between obtaining energy from supply company and consumers generating their own. In No. 1 test the mill worked from Monday to Saturday, night and day, and light was required all the hours of darkness in week days throughout the year. Consequently the number of hours during which the lamps burned are heavy—namely, 3,500. The working hours of Nos. 2 and 3 plants are 1,000 and 700 per annum respectively. Reference

to the total cost per unit will give some idea of the effect the number of lamp hours has upon this item.

Rate per unit due to interest, &c.—The low rate per unit in No. 1 (steam plant) is owing to the greater number of hours the installation is run. For instance, if the gas engine plant No. 2 was run for the same number of lamp hours, the cost would be reduced from 2·8*d.* to about ·95*d.*, or a total cost per unit of 1·8*d.* as against 1·4*d.* for steam (exclusive of boiler).

Total average cost.—In comparing the total cost per unit as herein given with the cost of energy from supply company—which varies from 4½*d.* to 8*d.* per unit—it must not be forgotten that to these latter amounts there must be added an additional sum for interest and depreciation upon the wiring and lamps, also renewals and transformer and meter rent, &c., which has been included in these costs of 1·4*d.*, 3¾*d.* and 3·9*d.* respectively.

The interest &c. rate is made up of 5 per cent. interest (3 or 4 per cent. might be fairer) on first cost.; 5 per cent. depreciation, cost of attendance, house rent, repair and renewals of lamps, &c., for portions under test.

DYNAMOS

No. 1 *Plant.*—24-unit four-pole compound-wound 'Tyne' dynamo, belt-driven, by Messrs. Ernest Scott and Mountain, Limited; constructed to supply current for 400 16-candle-power incandescent lamps.

No. 2 *Plant.*—24-unit two-pole compound-wound 'Tyne' dynamo, belt-driven; constructed to supply current for 400 16-candle-power incandescent lamps and set of accumulators for 100 16-candle-power lamps.

No. 3 *Plant.*—18-unit two-pole compound-wound 'Tyne' dynamo, belt-driven; constructed to supply current for 300 16-candle-power incandescent lamps.

No. 4 *Plant.*—16-kilowatt compound-wound dynamo, belt-driven; by Messrs. Lawrence Scott and Co. Output—152 ampères, 105 volts.

In the driving of dynamos a grave error is often made in the length of belt drive ; people used to steam engine practice look to long drives as the correct thing—with the result that an excessive oscillation and wave motion is given to the belt, which seriously affects the running of the dynamo and the steadiness of the light.

The centres of engine and dynamo should not exceed 18 feet or be less than 12 feet.

INDEX

S

PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
LONDON

April, 1896.

A

CLASSIFIED CATALOGUE

OF

SCIENTIFIC WORKS

PUBLISHED BY

MESSRS. LONGMANS, GREEN, & CO.

LONDON: 39 PATERNOSTER ROW, E.C.

NEW YORK: 91 & 93 FIFTH AVENUE.
BOMBAY: 32 HORNBY ROAD.

CONTENTS.

CHEMISTRY.

ADDYMAN—Agricultural Analysis. A Manual of Quantitative Analysis for Students of Agriculture. By FRANK T. ADDYMAN, B.Sc. (Lond.), F.I.C. With 49 Illustrations. Crown 8vo. 5*s.* net.

CARNEGIE—Law and Theory in Chemistry: a Companion Book for Students. By DOUGLAS CARNEGIE, sometime Scholar and Demonstrator in Chemistry of Gonville and Caius, Cambridge. Cr. 8vo. 6*s.*

COLEMAN & ADDYMAN—Practical Agricultural Chemistry. For Elementary Students, adapted for use in Agricultural Classes and Colleges. By J. BERNARD COLEMAN, A.R.C.Sc., F.I.C., and FRANK T. ADDYMAN, B.Sc. (Lond.) F.I.C. With 24 Illustrations. Crown 8vo. 1*s.* 6*d.* net.

CORNISH—Practical Proofs of Chemical Laws: a Course of Experiments upon the Combining Proportions of the Chemical Elements. By VAUGHAN CORNISH, M.Sc., Associate of the Owens College, Manchester. Crown 8vo. 2*s.*

CROOKES—Select Methods in Chemical Analysis, chiefly Inorganic. By WILLIAM CROOKES, F.R.S., &c., Editor of the *Chemical News.* With 67 Woodcuts. 8vo. 21*s.* net.

EARL—The Elements of Laboratory Work: a Course of Natural Science. By A. G. EARL, M.A., F.C.S., late Scholar of Christ's College, Cambridge. With 57 Diagrams and numerous Exercises and Questions. Crown 8vo. 4*s.* 6*d.*

FURNEAUX—Elementary Chemistry, Inorganic and Organic. By W. FURNEAUX, F.R.C.S., Lecturer on Chemistry, London School Board. With 65 Illustrations and 155 Experiments. Crown 8vo. 2*s.* 6*d.*

HJELT—Principles of General Organic Chemistry. By Professor E. HJELT, of Helsingfors. Translated from the German by J. BISHOP TINGLE, Ph.D., Assistant in the Laboratory of the Heriot Watt College, Edinburgh. Crown 8vo. 6*s.* 6*d.*

JAGO—Works by W. JAGO, F.C.S., F.I.C.

—— **Inorganic Chemistry, Theoretical and Practical.** With an Introduction to the Principles of Chemical Analysis Inorganic and Organic. With numerous Experiments, with 63 Woodcuts and numerous Questions and Exercises. Fcp. 8vo. 2s. 6d

—— **An Introduction to Practical Inorganic Chemistry.** Crown 8vo. 1*s.* 6*d.*

—— **Inorganic Chemistry, Theoretical and Practical.** A Manual for Students in Advanced Classes of the Science and Art Department. With Plate of Spectra and 78 Woodcuts. Crown 8vo. 4*s.* 6*d.*

KOLBE—A Short Text-Book of Inorganic Chemistry. By Dr. HERMANN KOLBE. Translated and Edited by T. S. HUMPIDGE, Ph.D. With 66 Illustrations. Crown 8vo. 8*s.* 6*d.*

MENDELÉEFF—The Principles of Chemistry. By D. MENDELÉEFF, Professor of Chemistry in the University of St. Petersburg. Translated by GEORGE KAMENSKY, A.R.S.M., of the Imperial Mint, St. Petersburg, and edited by A. J. GREENAWAY, F.I.C., Sub-Editor of the Journal of the Chemical Society. With 97 Illustrations. 2 vols. 8vo. 36*s.*

MEYER—Outlines of Theoretical Chemistry. By LOTHAR MEYER, Professor of Chemistry in the University of Tübingen. Translated by Professors P. PHILLIPS BEDSON, D.Sc., and W. CARLETON WILLIAMS, B.Sc. 8vo. 9*s.*

MILLER—Introduction to the Study of Inorganic Chemistry. By WILLIAM ALLEN MILLER, M.D., LL.D., F.R.S. With 71 Woodcuts. Fcp. 8vo. 3*s.* 6*d.*

MUIR—Works by M. M. PATTISON MUIR, M.A., Fellow of Gonville and Caius College, Cambridge.

——— **The Alchemical Essence and the Chemical Element:** an Episode in the Quest of the Unchanging. 8vo. 4*s.* 6*d.*

——— **Tables and Directions for the Qualitative Chemical Analysis** of Moderately Complex Mixtures of Salts. Crown 8vo. 1*s.* 6*d.*

NEWTH—Works by G. S. NEWTH, Royal College of Science, South Kensington.

——— **Chemical Lecture Experiments.** With 224 Diagrams. Crown 8vo. 10*s.* 6*d.*

——— **A Text-Book of Inorganic Chemistry.** With 146 Illustrations. Crown 8vo. 6*s.* 6*d.*

———**Elementary Practical Chemistry.** A Laboratory Manual for Use in Organised Science Schools. With 108 Illustrations and 254 Experiments. Crown 8vo. 2*s.* 6*d.*

ODLING—A Course of Practical Chemistry, arranged for the Use of Medical Students, with express reference to the Three Months' Summer Practice. By WILLIAM ODLING, M.A. With 71 Woodcuts. Crown 8vo. 6*s.*

OSTWALD—Solutions. By W. OSTWALD, Professor of Chemistry in the University of Leipzig. Being the Fourth Book, with some Additions, of the Second Edition of Ostwald's 'Lehrbuch der Allgemeinen Chemie'. Translated by M. M. PATTISON MUIR, Fellow of Gonville and Caius College, Cambridge. 8vo. 10*s.* 6*d.*

PAYEN—Industrial Chemistry. A Manual for use in Technical Colleges and Schools, based upon a Translation of Stohmann and Engler's German Edition of PAYEN'S 'Précis de Chimie Industrielle'. Edited by B. H. PAUL, Ph.D. With 698 Woodcuts. 8vo. 42*s.*

REYNOLDS—Experimental Chemistry for Junior Students. By J. EMERSON REYNOLDS, M.D., F.R.S., Professor of Chemistry, University of Dublin; Examiner in Chemistry, University of London. Fcp. 8vo. with numerous Woodcuts.

Part I. Introductory. Fcp. 8vo. 1*s.* 6*d.*

Part II. Non-Metals, with an Appendix on Systematic Testing for Acids. Fcp. 8vo. 2*s.* 6*d.*

Part III. Metals and Allied Bodies. Fcp. 8vo. 3*s.* 6*d.*

Part IV. Carbon Compounds. Fcp. 8vo. 4*s.*

SHENSTONE—Works by W. A. SHENSTONE, Lecturer on Chemistry in Clifton College.

——— **The Methods of Glass-Blowing.** For the use of Physical and Chemical Students. With 42 Illustrations. Crown 8vo. 1*s.* 6*d.*

——— **A Practical Introduction to Chemistry.** Intended to give a Practical Acquaintance with the Elementary Facts and Principles of Chemistry. With 25 Illustrations. Crown 8vo. 2*s.*

THORPE—**A Dictionary of Applied Chemistry.** . By T. E. THORPE, B.Sc. (Vict.), Ph.D., F.R.S., Treas. C.S., Professor of Chemistry in the Royal College of Science, South Kensington. Assisted by Eminent Contributors. 3 vols. 8vo. Vols. I. & II. 42*s.* each. Vol. III. 63*s.*

——— **Quantitative Chemical Analysis.** By T. E. THORPE, Ph.D., F.R.S. With 88 Woodcuts. Fcp. 8vo. 4*s.* 6*d.*

THORPE and MUIR—**Qualitative Chemical Analysis and Laboratory** Practice. By T. E. THORPE, Ph.D., D.Sc., F.R.S., and M. M. PATTISON MUIR, M.A. With Plate of Spectra and 57 Woodcuts. Fcp. 8vo. 3*s.* 6*d.*

TILDEN—Works by WILLIAM A. TILDEN, D.Sc. (Lond.), F.C.S., Professor of Chemistry at the Royal College of Science.

——— **Introduction to the Study of Chemical Philosophy.** The Principles of Theoretical and Systematic Chemistry. With 5 Woodcuts. With or without the ANSWERS of Problems. Fcp. 8vo. 4*s.* 6*d.*

——— **Practical Chemistry.** The Principles of Qualitative Analysis. Fcp. 8vo. 1*s.* 6*d.*

——— **Hints on the Teaching of Elementary Chemistry in Schools** and Science Classes. Cr. 8vo. 2*s.*

WATTS' Dictionary of Chemistry. Revised and entirely Rewritten by H. FORSTER MORLEY, M.A., D.Sc., Fellow of, and lately Assistant-Professor of Chemistry in, University College, London ; and M. M. PATTISON MUIR, M.A., F.R.S.E., Fellow, and Prælector in Chemistry, of Gonville and Caius College, Cambridge. Assisted by Eminent Contributors. 4 vols. 8vo. Vols. I. & II., 42*s.* each. Vol. III., 50*s.* Vol. IV., 63*s.*

WHITELEY—Works by R. LLOYD WHITELEY, F.I.C., Principal of the Municipal Science School, West Bromwich.

——— **Chemical Calculations,** with Explanatory Notes, Problems and Answers, specially adapted for use in Colleges and Science Schools. With a Preface by Professor F. CLOWES, D.Sc. (Lond.), F.I.C. Crown 8vo. 2*s.*

——— **Organic Chemistry.** The Fatty Compounds. With 45 Illustrations. Crown 8vo. 3*s.* 6*d.*

PHYSICS.

COOK—Physics. (Specially adapted for Indian Schools and Students.) By J. COOK, M.A., Principal, Central College, Bangalore. With Examination Questions and 206 Illustrations. Crown 8vo. 2s. *6d.*

EARL—The Elements of Laboratory Work: a Course of Natural Science. By A. G. EARL, M.A., F.C.S. With 57 Diagrams and numerous Exercises, etc. Crown 8vo. 4s. *6d.*

GANOT—Works by Professor GANOT. Translated and Edited by E. ATKINSON, Ph.D., F.C.S.

——— **Elementary Treatise on Physics,** Experimental and Applied. With 9 Coloured Plates and 1028 Woodcuts. Crown 8vo. 15s.

——— **Natural Philosophy for General Readers and Young Persons;** a Course of Physics divested of Mathematical Formulæ, expressed in the language of daily life. With 7 Plates, 624 Woodcuts, and an Appendix of Questions. Crown 8vo. 7s. *6d.*

GLAZEBROOK and SHAW—Practical Physics. By R. T. GLAZEBROOK, M.A., F.R.S., and W. N. SHAW. M.A. 134 Woodcuts. Fcp. 8vo. 7s. *6d.*

GUTHRIE—A Class-Book of Practical Physics. Molecular Physics and Sound. By F. GUTHRIE, Ph.D. With 91 Diagrams. Fcp. 8vo. 1s. *6d.*

HELMHOLTZ—Popular Lectures on Scientific Subjects. By HERMANN VON HELMHOLTZ. Translated by E. ATKINSON, Ph.D., F.C.S., formerly Professor of Experimental Science, Staff College. With 68 Illustrations. 2 vols., crown 8vo. 3s. *6d.* each.

Vol. I.—The Relation of Natural Science to Science in General—Goethe's Scientific Researches—The Physiological Causes of Harmony in Music—Ice and Glaciers—The Inter-action of the Natural Forces—The Recent Progress of the Theory of Vision—The Conservation of Force—The Aim and Progress of Physical Science.

Vol. II.—Gustav Magnus. In Memoriam—The Origin and Significance of Geometrical Axioms—The Relations of Optics to Painting—The Origin of the Planetary System—Thought in Medicine—Academic Freedom in German Universities—Hermann von Helmholtz. An Autobiographical Sketch.

HENDERSON—Elementary Physics. By JOHN HENDERSON, B.Sc. (Edin.), A.I.E.E., Lecturer in Physics, Municipal Technical School, Manchester. Crown 8vo. 2s. *6d.*

HOPKINS—Preparatory Physics: a Short Course in the Laboratory. By WILLIAM J. HOPKINS, Professor of Physics in the Drexel Institute, Philadelphia. With numerous Diagrams. 8vo. 5s.

WATSON—Elementary Practical Physics: a Laboratory Manual for Use in Organised Science Schools. By W. WATSON, B.Sc., Demonstrator in Physics in the Royal College of Science, London; Assistant Examiner in Physics, Science and Art Department.

WORTHINGTON—A First Course of Physical Laboratory Practice. Containing 264 Experiments. By A. M. WORTHINGTON, F.R.S., M.A. With Illustrations. Crown 8vo. 4s. *6d.*

WRIGHT—Elementary Physics. By MARK R. WRIGHT, Professor of Normal Education, Durham College of Science. With 242 Illustrations. Crown 8vo. 2s. *6d.*

MECHANICS AND MECHANISM.

BALL—A Class-Book of Mechanics. By Sir R. S. BALL, LL.D. 89 Diagrams. Fcp. 8vo. 1*s.* 6*d.*

GOODEVE—Works by T. M. GOODEVE, M.A., Professor of Mechanics at the Normal School of Science, and the Royal School of Mines.

——— **Principles of Mechanics.** With 253 Woodcuts and numerous Examples. Crown 8vo. 6*s.*

——— **The Elements of Mechanism.** With 342 Woodcuts. Crown 8vo. 6*s.*

——— **A Manual of Mechanics:** an Elementary Text-book for Students of Applied Mechanics. With 138 Illustrations and Diagrams, and 188 Examples taken from the Science Department Examination Papers, with Answers. Fcp. 8vo. 2*s.* 6*d.*

GRIEVE—Lessons in Elementary Mechanics. By W. H. GRIEVE, P.S.A., late Engineer R.N., Science Demonstrator for the London School Board, &c. Stage 1. With 165 Illustrations and a large number of Examples. Fcp. 8vo. 1*s.* 6*d.* Stage 2. With 122 Illustrations. Fcp. 8vo. 1*s.* 6*d.* Stage 3. With 103 Illustrations. Fcp. 8vo 1*s.* 6*d.*

MAGNUS—Lessons in Elementary Mechanics. Introductory to the Study of Physical Science. Designed for the Use of Schools, and of Candidates for the London Matriculation and other Examinations. With numerous Exercises, Examples, and Examination Questions and Solutions, &c., from 1870 to 1895. With Answers, and 131 Woodcuts. By Sir PHILIP MAGNUS, B.Sc., B.A. Fcp. 8vo. 3*s.* 6*d.*

Key for the use of Teachers only, price 5*s.* 3½*d.* net, *post free, from the publishers only.*

TAYLOR—Works by J. E. TAYLOR, M.A., B.Sc., Central Schools, Sheffield.

——— **Theoretical Mechanics,** including Hydrostatics and Pneumatics. With 175 Diagrams and Illustrations, and 522 Examination Questions and Answers. Crown 8vo. 2*s.* 6*d.*

——— **Theoretical Mechanics: Solids.** With 163 Illustrations, 120 Worked Examples, and over 500 Examples from Examination Papers, &c. Crown 8vo. 2*s.* 6*d.*

——— **Theoretical Mechanics: Fluids.** With 122 Illustrations, numerous Worked Examples, and about 500 Examples from Examination Papers, &c. Crown 8vo. 2*s.* 6*d.*

THORNTON—Theoretical Mechanics: Solids. Including Kinematics, Statics, and Kinetics. By ARTHUR THORNTON, M.A., F.R.A.S., late Scholar of Christ's College, Cambridge; Senior Science Master, Bradford Grammar School. With 220 Illustrations, 130 Worked Examples, and over 900 Examples from Examination Papers, &c. Crown 8vo. 4*s.* 6*d.*

TWISDEN—Works by the Rev. JOHN F. TWISDEN, M.A.

——— **Practical Mechanics;** an Elementary Introduction to their Study. With 855 Exercises and 184 Figures and Diagrams. Crown 8vo. 10*s.* 6*d.*

——— **Theoretical Mechanics.** With 172 Examples, numerous Exercises, and 154 Diagrams. Crown 8vo. 8*s.* 6*d.*

DYNAMICS, STATICS, AND HYDROSTATICS.

GELDARD—**Statics and Dynamics** By C. GELDARD, M.A., formerly Scholar of Trinity College, Cambridge, Mathematical Lecturer under the Non-Collegiate Students' Board, Cambridge. Crown 8vo. 5*s.*

GROSS—**Elementary Dynamics** (Kinematics and Kinetics). By E. J. GROSS, M.A., Fellow of Gonville and Caius College, Cambridge. Crown 8vo. 5*s.* 6*d.*

MAGNUS—**Hydrostatics and Pneumatics.** By Sir PHILIP MAGNUS, B.Sc. Fcp. 8vo. 1*s.* 6*d.*, or, with Answers, 2*s.*

*** The Worked Solutions of the Problems. 2*s.*

ROBINSON—**Elements of Dynamics** (Kinetics and Statics). With numerous Exercises. A Text-Book for Junior Students. By the Rev. J. L. ROBINSON, B.A., Chaplain and Naval Instructor at the Royal Naval College, Greenwich. Crown 8vo. 6*s.*

SMITH—**Graphics:** or, The Art of Calculation by Drawing Lines, applied especially to Mechanical Engineering. By ROBERT H. SMITH, Prof. of Engineering, Mason College, Birmingham. Part I. Arithmetic, Algebra, Trigonometry, Moments, Vector Addition. Locor Addition, Machine Kinematics, and Statics of Flat and Solid Structures. With separate Atlas of 29 Plates containing 97 Diagrams. 8vo. 15*s.*

SMITH—Works by J. HAMBLIN SMITH, M.A., of Gonville and Caius College, Cambridge.

——— **Elementary Statics.** Crown 8vo. 3*s.*

——— **Elementary Hydrostatics.** Crown 8vo. 3*s.*

——— **Key to Statics and Hydrostatics.** Crown 8vo. 6*s.*

WILLIAMSON—**Introduction to the Mathematical Theory of the** Stress and Strain of Elastic Solids. By BENJAMIN WILLIAMSON, D.Sc., D.C.L., F.R.S., Fellow and Senior Tutor of Trinity College, Dublin. Crown 8vo. 5*s*

WILLIAMSON and TARLETON—An Elementary Treatise on Dynamics. Containing Applications to Thermodynamics, with numerous Examples. By BENJAMIN WILLIAMSON, D.Sc., F.R.S., and FRANCIS A. TARLETON, LL.D. Crown 8vo. 10*s.* 6*d.*

WORTHINGTON—Dynamics of Rotation: an Elementary Introduction to Rigid Dynamics. By A. M. WORTHINGTON, M.A., F.R.S., Head Master and Professor of Physics at the Royal Naval Engineering College, Devonport. Crown 8vo. 3*s.* 6*d.*

SOUND, LIGHT, HEAT & THERMODYNAMICS.

ALEXANDER—Treatise on Thermodynamics. By PETER ALEXANDER, M.A., Lecturer on Mathematics, Queen Margaret College, Glasgow. Crown 8vo. 5*s.*

CUMMING—Heat. For the use of Schools and Students. By LINNÆUS CUMMING, M.A., late Scholar of Trinity College, Cambridge; Assistant Master at Rugby School. With numerous Illustrations. Crown 8vo. 4*s.* 6*d.*

DAY—Numerical Examples in Heat. By R. E. DAY, M.A. Fcp. 8vo. 3*s.* 6*d.*

HELMHOLTZ—On the Sensations of Tone as a Physiological Basis for the Theory of Music. By HERMANN VON HELMHOLTZ. Royal 8vo. 28*s.*

MADAN—An Elementary Text-Book on Heat. For the use of Schools. By H. G. MADAN, M.A., F.C.S., Fellow of Queen's College, Oxford; late Assistant Master at Eton College. Crown 8vo. 9*s.*

MAXWELL—Theory of Heat. By J. CLERK MAXWELL, M.A., F.R.SS., L. & E. With Corrections and Additions by Lord RAYLEIGH. With 38 Illustrations. Fcp. 8vo. 4*s.* 6*d.*

SMITH (J. Hamblin)—The Study of Heat. By J. HAMBLIN SMITH, M.A., of Gonville and Caius College, Cambridge. Cr. 8vo. 3*s.*

TYNDALL—Works by JOHN TYNDALL, D.C.L., F.R.S. See page 12.

WORMELL—A Class-Book of Thermodynamics. By RICHARD WORMELL, B.Sc., M.A. Fcp. 8vo. 1*s.* 6*d.*

WRIGHT—Works by MARK R. WRIGHT (Hon. Inter., B.Sc., London).

—— **Sound, Light, and Heat.** With 160 Diagrams and Illustrations Crown 8vo. 2*s.* 6*d.*

—— **Advanced Heat.** With 136 Diagrams and numerous Examples and Examination Papers. Crown 8vo. 4*s.* 6*d.*

STEAM AND THE STEAM ENGINE, &c.

BALE—A Handbook for Steam Users; being Rules for Engine Drivers and Boiler Attendants, with Notes on Steam Engine and Boiler Management and Steam Boiler Explosions. By M. POWIS BALE, M.I.M.E., A.M.I.C.E. Fcp. 8vo. 2*s.* 6*d.*

BOLTON—Motive Powers and their Practical Selection. By REGINALD BOLTON, Associate Member of the Institution of Civil Engineers, etc. Crown 8vo. 6*s.* 6*d.* net.

BOURNE—A Catechism of the Steam Engine, in its Various Applications in the Arts, to which is added a chapter on Air and Gas Engines, and another devoted to Useful Rules, Tables, and Memoranda. By JOHN BOURNE, C.E. Illustrated by 212 Woodcuts. Crown 8vo. 7*s.* 6*d.*

CLERK—The Gas Engine. By DUGALD CLERK. With 101 Woodcuts. Crown 8vo.

HOLMES—The Steam Engine. By GEORGE C. V. HOLMES (Whitworth Scholar), Secretary of the Institution of Naval Architects. With 212 Woodcuts. Fcp. 8vo. 6*s.*

RANSOM—Steam and Gas Engine Governors. By H. B. RANSOM. [*In preparation.*

RIPPER—Works by WILLIAM RIPPER, Member of the Institution of Mechanical Engineers; Professor of Mechanical Engineering in the Sheffield Technical School.

——— **Steam.** With 142 Illustrations. Crown 8vo. 2*s.* 6*d.*

SENNETT—The Marine Steam Engine. A Treatise for the Use of Engineering Students and Officers of the Royal Navy. By RICHARD SENNETT, R.N., Engineer-in-Chief of the Royal Navy. With 261 Illustrations. 8vo. 21*s.*

STROMEYER—Marine Boiler Management and Construction. Being a Treatise on Boiler Troubles and Repairs, Corrosion, Fuels, and Heat, on the properties of Iron and Steel, on Boiler Mechanics, Workshop Practices, and Boiler Design. By C. E. STROMEYER, Graduate of the Royal Technical College at Aix-la-Chapelle, Member of the Institute of Naval Architects, etc. With 452 Illustrations. 8vo. 18*s.* net.

ARCHITECTURE.

GWILT—An Encyclopædia of Architecture. By JOSEPH GWILT, F.S.A. Illustrated with more than 1100 Engravings on Wood. Revised (1888), with Alterations and Considerable Additions, by WYATT PAPWORTH. 8vo. 52*s*. 6*d*.

MITCHELL—The Stepping-Stone to Architecture: explaining in simple language the Principles and Progress of Architecture from the earliest times. By THOMAS MITCHELL. With 22 Plates and 49 Woodcuts. 18mo. 1*s*. sewed.

BUILDING CONSTRUCTION.

Advanced Building Construction. By the Author of 'Rivington's Notes on Building Construction'. With 385 Illustrations. Crown 8vo. 4*s*. 6*d*.

BURRELL—Building Construction. By EDWARD J. BURRELL, Second Master of the People's Palace Technical School, London. With 303 Working Drawings. Crown 8vo. 2*s*. 6*d*.

SEDDON—Builder's Work and the Building Trade. By Colonel H. C. SEDDON, R.E., Superintending Engineer H.M.'s Dockyard, Portsmouth; Examiner in Building Construction, Science and Art Department, South Kensington. With numerous Illustrations. Medium 8vo. 16*s*.

RIVINGTON'S COURSE OF BUILDING CONSTRUCTION.

Notes on Building Construction. Arranged to meet the requirements of the Syllabus of the Science and Art Department of the Committee of Council on Education, South Kensington. Medium 8vo.

Part I. First Stage, or Elementary Course. With 552 Woodcuts. 10*s*. 6*d*.

Part II. Commencement of Second Stage, or Advanced Course. With 479 Woodcuts. 10*s*. 6*d*.

Part III. Materials. Advanced Course, and Course for Honours. With 188 Woodcuts. 21*s*.

Part IV. Calculations for Building Structures. Course for Honours. With 597 Woodcuts. 15*s*.

ELECTRICITY AND MAGNETISM.

BENJAMIN—The Intellectual Rise in Electricity: a History. By PARK BENJAMIN, Ph.D., LL.B., Member of the American Institute of Mechanical Engineers, etc. With 28 Portraits and Illustrations. 8vo. 21*s*.

CUMMING—Electricity treated Experimentally. For the use of Schools and Students. By LINNÆUS CUMMING, M.A., Assistant Master in Rugby School. With 242 Illustrations. Crown 8vo. 4*s*. 6*d*.

DAY—Exercises in Electrical and Magnetic Measurements, with Answers. By R. E. DAY. 12mo. 3*s*. 6*d*.

DU BOIS—The Magnetic Circuit in Theory and Practice. By Dr. H. Du Bois, Privatdocent in the University of Berlin. Tranlated by Dr. Atkinson, formerly Professor of Experimental Science in the Staff College, Sandhurst. With 94 Illustrations. 8vo. 12*s.* net.

GORE—The Art of Electro-Metallurgy, including all known Processes of Electro-Deposition. By G. Gore, LL.D., F.R.S. With 56 Woodcuts. Fcp. 8vo. 6*s.*

JENKIN—Electricity and Magnetism. By Fleeming Jenkin, F.R.S.S., L. & E., M.I.C.E. With 177 Illustrations. Fcp. 8vo. 3*s.* 6*d.*

JOUBERT—Elementary Treatise on Electricity and Magnetism. Founded on Joubert's 'Traité Élémentaire d'Électricité.' By G. C. Foster, F.R.S., Quain Professor of Physics in University College, London; and E. Atkinson, Ph.D., formerly Professor of Experimental Science in the Staff College. With 381 Illustrations. Crown 8vo. 7*s.* 6*d.*

LARDEN—Electricity for Public Schools and Colleges. By W. Larden, M.A. With 215 Illustrations and a Series of Examination Papers with Answers. Crown 8vo. 6*s.*

MERRIFIELD—Magnetism and Deviation of the Compass. For the use of Students in Navigation and Science Schools. By John Merrifield, LL.D., F.R.A.S. 18mo. 2*s.* 6*d.*

POYSER—Works by A. W. Poyser, M.A., Grammar School, Wisbech.

——— **Magnetism and Electricity.** With 235 Illustrations. Cr. 8vo. 2*s.* 6*d.*

——— **Advanced Electricity and Magnetism.** With 317 Illustrations. Crown 8vo. 4*s.* 6*d.*

SLINGO and BROOKER—Works by W. Slingo and A. Brooker.

——— **Electrical Engineering for Electric Light Artisans and Students.** With 346 Illustrations. Crown 8vo. 12*s.*

——— **Problems and Solutions in Elementary Electricity and Magnetism.** Embracing a Complete Set of Answers to the South Kensington Papers for the Years 1885-1894, and a Series of Original Questions. With 67 Original Illustrations. Crown 8vo. 2*s.*

TYNDALL—Works by John Tyndall, D.C.L., F.R.S. *See p.* 12.

TELEGRAPHY AND THE TELEPHONE.

BENNETT—The Telephone Systems of the Continent of Europe. By A. R. Bennett, Member of the Institution of Electrical Engineers; Divisional Engineering Superintendent in London to the United Telephone Company, Limited, 1880. With 169 Illustrations. Cr. 8vo. 15*s.*

CULLEY—A Handbook of Practical Telegraphy. By R. S. Culley M.I.C.E., late Engineer-in-Chief of Telegraphs to the Post Office. With 135 Woodcuts and 17 Plates. 8vo. 16*s.*

PREECE and SIVEWRIGHT—Telegraphy. By W. H. Preece, C.B., F.R.S., V.P. Inst. C.E., &c., Engineer-in-Chief and Electrician, Post Office Telegraphs; and Sir J. Sivewright, K.C.M.G., General Manager, South African Telegraphs. With 258 Woodcuts. Fcp. 8vo. 6*s.*

WORKS BY JOHN TYNDALL,

D.C.L., LL.D., F.R.S.

Fragments of Science: a Series of Detached Essays, Addresses and Reviews. 2 vols. Crown 8vo. 16*s.*

VOL. I. :—The Constitution of Nature—Radiation—On Radiant Heat in relation to the Colour and Chemical Constitution of Bodies—New Chemical Reactions produced by Light—On Dust and Disease—Voyage to Algeria to observe the Eclipse—Niagara—The Parallel Roads of Glen Roy—Alpine Sculpture—Recent Experiments on Fog-Signals—On the Study of Physics—On Crystalline and Slaty Cleavage—On Paramagnetic and Diamagnetic Forces—Physical Basis of Solar Chemistry—Elementary Magnetism—On Force—Contributions to Molecular Physics—Life and Letters of FARADAY—The Copley Medalist of 1870—The Copley Medalist of 1871—Death by Lightning.—Science and the Spirits.

VOL. II. :—Reflections on Prayer and Natural Law—Miracles and Special Providences—On Prayer as a Form of Physical Energy—Vitality—Matter and Force—Scientific Materialism—An Address to Students—Scientific Use of the Imagination—The Belfast Address—Apology for the Belfast Address—The Rev. JAMES MARTINEAU and the Belfast Address—Fermentation, and its Bearings on Surgery and Medicine—Spontaneous Generation—Science and Man—Professor VIRCHOW and Evolution—The Electric Light.

New Fragments. Crown 8vo. 10*s.* 6*d.*

CONTENTS :—The Sabbath—Goethe's 'Farbenlehre'—Atoms, Molecules and Ether Waves—Count Rumford—Louis Pasteur, his Life and Labours—The Rainbow and its Congeners—Address delivered at the Birkbeck Institution on 22nd October, 1884—Thomas Young—Life in the Alps—About Common Water—Personal Recollections of Thomas Carlyle—On Unveiling the Statue of Thomas Carlyle—On the Origin, Propagation and Prevention of Phthisis—Old Alpine Jottings—A Morning on Alp Lusgen.

The Glaciers of the Alps: being a Narrative of Excursions and Ascents. An Account of the Origin and Phenomena of Glaciers, and an Exposition of the Physical Principles to which they are related. With numerous Illustrations. Crown 8vo. 6*s.* 6*d.* net.

Lectures on Sound. With Frontispiece of Fog-Syren, and 203 other Woodcuts and Diagrams in the Text. Crown 8vo. 10*s.* 6*d.*

Heat, a Mode of Motion. With 125 Woodcuts and Diagrams. Cr. 8vo. 12*s.*

Lectures on Light delivered in the United States in 1872 and 1873. With Portrait, Lithographic Plate and 59 Diagrams. Crown 8vo. 5*s.*

Essays on the Floating Matter of the Air in relation to Putrefaction and Infection. With 24 Woodcuts. Crown 8vo. 7*s.* 6*d.*

Faraday as a Discoverer. Crown 8vo. 3*s.* 6*d.*

Researches on Diamagnetism and Magnecrystallic Action; including the Question of Diamagnetic Polarity. Crown 8vo. 12*s.*

Notes of a Course of Nine Lectures on Light, delivered at the Royal Institution of Great Britain, 1869. Crown 8vo. 1*s.* 6*d.*

Notes of a Course of Seven Lec-tures on Electrical Phenomena and Theories, delivered at the Royal Institution of Great Britain, 1870. Cr. 8vo. 1*s.* 6*d.*

Lessons in Electricity at the Royal Institution, 1875-1876. With 58 Woodcuts and Diagrams. Crown 8vo. 2*s.* 6*d.*

ENGINEERING, STRENGTH OF MATERIALS, &c.

ANDERSON—The Strength of Materials and Structures: the Strength of Materials as depending on their Quality and as ascertained by Testing Apparatus. By Sir J. ANDERSON, C.E., LL.D., F.R.S.E. With 66 Woodcuts. Fcp. 8vo. 3*s.* 6*d.*

BARRY—Railway Appliances: a Description of Details of Railway Construction subsequent to the Completion of the Earthworks and Structures. By JOHN WOLFE BARRY, C.B., M.I.C.E. With 218 Woodcuts. Fcp. 8vo. 4*s.* 6*d.*

STONEY—The Theory of the Stresses on Girders and Similar Structures. With Practical Observations on the Strength and other Properties of Materials. By BINDON B. STONEY, LL.D., F.R.S., M.I.C.E. With 5 Plates and 143 Illustrations in the Text. Royal 8vo. 36*s.*

UNWIN—Works by W. CAWTHORNE UNWIN, B.Sc., M.Inst. Civil Engineers.

—— **The Testing of Materials of Construction.** Embracing the Description of Testing Machinery and Apparatus Auxiliary to Mechanical Testing, and an Account of the most Important Researches on the Strength of Materials. With 141 Woodcuts and 5 folding-out Plates. 8vo. 21*s.*

—— **On the Development and Transmission of Power from Central Stations:** being the Howard Lectures delivered at the Society of Arts in 1893. With 81 Diagrams. 8vo. 10*s.* net.

WARREN—Engineering Construction in Iron, Steel, and Timber. By WILLIAM HENRY WARREN, Whitworth Scholar; Member of the Institution of Civil Engineers, London; Challis Professor of Civil and Mechanical Engineering, University of Sydney. With 13 Folding Plates and 375 Diagrams. Royal 8vo. 16*s.* net.

LONGMANS' CIVIL ENGINEERING SERIES.

Edited by the Author of 'Notes on Building Construction'.

Tidal Rivers: their Hydraulics, Improvement and Navigation. By W. H. WHEELER, M.Inst.C.E., Author of 'The Drainage of Fens and Low Lands by Gravitation and Steam Power'. With 75 Illustrations. Medium 8vo. 16*s.* net.

Notes on Docks and Dock Construction. By C. COLSON, M.Inst.C.E., Assistant Director of Works, Admiralty. With 365 Illustrations. Medium 8vo. 21*s.* net.

Principle and Practice of Harbour Construction. By WILLIAM SHIELD, F.R.S.E., M.Inst.C.E., and Executive Engineer, Natural Harbour Refuge, Peterhead, N.B. With 97 Illustrations. Medium 8vo. 15*s.* net.

Railway Construction. By W. H. MILLS, M.Inst.C.E., Engineer-in-Chief, Great Northern Railway, Ireland. [*In preparation.*

Calculations for Engineering Structures. By T. CLAXTON FIDLER, M.Inst.C.E., Professor of Engineering in the University of Dundee; Author of 'A Practical Treatise on Bridge Construction'. [*In preparation.*

The Student's Course of Civil Engineering. By L. F. VERNON-HARCOURT, M.Inst.C.E., Professor of Civil Engineering at University College. [*In preparation.*

WORKSHOP APPLIANCES, &c.

NORTHCOTT—Lathes and Turning, Simple, Mechanical and Ornamental. By W. H. Northcott. With 338 Illustrations. 8vo. 18*s*.

SHELLEY—Workshop Appliances, including Descriptions of some of the Gauging and Measuring Instruments, Hand-cutting Tools, Lathes, Drilling, Planing and other Machine Tools used by Engineers. By C. P. B. Shelley, M.I.C.E. With 323 Woodcuts. Fcp. 8vo. 5*s*.

MINERALOGY, METALLURGY, &c.

BAUERMAN—Works by Hilary Bauerman, F.G.S.

——— **Systematic Mineralogy.** With 373 Woodcuts and Diagrams. Fcp. 8vo. 6*s*.

——— **Descriptive Mineralogy.** With 236 Woodcuts and Diagrams. Fcp. 8vo. 6*s*.

BLOXAM and HUNTINGTON—Metals: their Properties and Treatment. By C. L. Bloxam and A. K. Huntington, Professors in King's College, London. With 130 Woodcuts. Fcp. 8vo. 5*s*.

GORE—The Art of Electro-Metallurgy, including all known Processes of Electro-Deposition. By G. Gore, LL.D., F.R.S. With 56 Woodcuts. Fcp. 8vo. 6*s*.

LUPTON—Mining. An Elementary Treatise on the Getting of Minerals. By Arnold Lupton, M.I.C.E., F.G.S., etc., Mining Engineer, Professor of Coal Mining at the Victoria University, Yorkshire College, Leeds. With 596 Illustrations. Crown 8vo. 9*s*. net.

MITCHELL—A Manual of Practical Assaying. By John Mitchell, F.C.S. Revised, with the Recent Discoveries incorporated. By W. Crookes, F.R.S. With 201 Illustrations. 8vo. 31*s*. 6*d*.

RHEAD—Metallurgy. An Elementary Text-Book. By E. C. Rhead, Lecturer on Metallurgy at the Municipal Technical School, Manchester. With 94 Illustrations. Crown 8vo. 3*s*. 6*d*.

RUTLEY—The Study of Rocks; an Elementary Text-Book of Petrology. By F. Rutley, F.G.S. With 6 Plates and 88 Woodcuts. Fcp. 8vo. 4*s*. 6*d*.

VON COTTA—Rocks Classified and Described: A Treatise on Lithology. By Bernhard Von Cotta. With English, German, and French Synonyms. Translated by Philip Henry Lawrence, F.G.S., F.R.G.S. Crown 8vo. 14*s*.

MACHINE DRAWING AND DESIGN.

LOW and BEVIS—A Manual of Machine Drawing and Design. By DAVID ALLAN LOW (Whitworth Scholar), M.I. Mech. E., Headmaster of the Technical School, People's Palace, London; and ALFRED WILLIAM BEVIS (Whitworth Scholar), M.I. Mech.E., Director of Manual Training to the Birmingham School Board. With over 700 Illustrations. 8vo. 7*s*. 6*d*.

LOW—An Introduction to Machine Drawing and Design. By DAVID ALLAN LOW, Headmaster of the Technical School, People's Palace, London. With 97 Illustrations and Diagrams. Crown 8vo. 2*s*.

——— **Improved Drawing Scales.** By DAVID ALLAN LOW. 4*d*. in case.

UNWIN—The Elements of Machine Design. By W. CAWTHORNE UNWIN, F.R.S., Part I. General Principles, Fastenings and Transmissive Machinery. With 304 Diagrams, &c. Crown 8vo. 6*s*. Part II. Chiefly on Engine Details. With 174 Woodcuts. Crown 8vo. 4*s*. 6*d*.

ASTRONOMY, NAVIGATION, &c.

ABBOTT—Elementary Theory of the Tides: the Fundamental Theorems Demonstrated without Mathematics, and the Influence on the Length of the Day Discussed. By T. K. ABBOTT, B.D., Fellow and Tutor, Trinity College, Dublin. Crown 8vo. 2*s*.

BALL—Works by Sir ROBERT S. BALL, LL.D., F.R.S.

——— **Elements of Astronomy.** With 136 Diagrams. Fcp. 8vo. 6*s*.

——— **A Class-Book of Astronomy.** With 41 Diagrams. Fcp. 8vo. 1*s*. 6*d*.

BRINKLEY—Astronomy. By F. BRINKLEY, formerly Astronomer Royal for Ireland. Re-edited and Revised by J. W. STUBBS, D.D., and F. BRUNNOW, Ph.D. With 49 Diagrams. Crown 8vo. 6*s*.

CLERKE—The System of the Stars. By AGNES M. CLERKE. With 6 Plates and numerous Illustrations. 8vo. 21*s*.

GIBSON—The Amateur Telescopist's Handbook. By FRANK M. GIBSON, Ph.D., LL.B. With 1 Plate and 13 Diagrams. Cr. 8vo. 3*s*. 6*d*.

HERSCHEL—Outlines of Astronomy. By Sir JOHN F. W. HERSCHEL, Bart., K.H., &c. With 9 Plates and numerous Diagrams. Crown 8vo. 12*s*.

MARTIN—Navigation and Nautical Astronomy. Compiled by Staff-Commander W. R. MARTIN, R.N. Royal 8vo. 18*s*.

MERRIFIELD—A Treatise on Navigation for the use of Students. By JOHN MERRIFIELD, LL.D., F.R.A.S., F.M.S. Crown 8vo. 5*s*.

ORCHARD—The Astronomy of Milton's Paradise Lost. By THOMAS N. ORCHARD, M.D., Member of the British Astronomical Association. With 13 Illustrations. 8vo. 15*s*.

WEBB—Celestial Objects for Common Telescopes. By the Rev. T. W. WEBB, M.A., F.R.A.S. Fifth Edition, Revised and greatly Enlarged, by the Rev. T. E. ESPIN, M.A., F.R.A.S. (2 vols.) Vol. I., with 2 Plates and numerous Illustrations. Crown 8vo. 6*s*. Vol. II., with Illustrations and Map of Star Spectra. Crown 8vo. 6*s*. 6*d*.

WORKS BY RICHARD A. PROCTOR.

Old and New Astronomy. With 21 Plates and 472 Illustrations in the Text. 4to. 21*s*.

Myths and Marvels of Astronomy. Crown 8vo. 5*s*. Silver Library Edition. Crown 8vo. 3*s* 6*d*.

The Moon: Her Motions, Aspect, Scenery, and Physical Condition. With many Plates and Charts, Wood Engraving, and 2 Lunar Photographs. Crown 8vo. 5*s*.

The Universe of Stars: Researches into, and New Views respecting, the Constitution of the Heavens. With 22 Charts (4 coloured) and 22 Diagrams. 8vo. 10*s*. 6*d*.

Other Worlds than Ours: the Plurality of Worlds Studied under the Light of Recent Scientific Researches. With 14 Illustrations; Map, Charts, &c. Crown 8vo. 5*s*. Cheap Edition. Crown 8vo. 3*s*. 6*d*.

Treatise on the Cycloid and all Forms of Cycloidal Curves, and on the Use of Cycloidal Curves in dealing with the Motions of Planets, Comets, &c. With 161 Diagrams. Crown 8vo. 10*s*. 6*d*.

The Orbs Around Us: Essays on the Moon and Planets, Meteors and Comets, the Sun and Coloured Pairs of Suns. Crown 8vo. 5*s*. Cheap Edition. Crown 8vo. 3*s*. 6*d*.

Light Science for Leisure Hours: Familiar Essays on Scientific Subjects, Natural Phenomena, &c. 3 vols. Cr. 8vo. 5*s*. each.

Our Place among Infinites: Essays contrasting our Little Abode in Space and Time with the Infinites around us. Crown 8vo. 5*s*.

The Expanse of Heaven: Essays on the Wonders of the Firmament. Cr. 8vo. 5*s*. Cheap Edition. Cr. 8vo. 3*s*. 6*d*.

Other Suns Than Ours: a Series of Essays on Suns—Old, Young, and Dead. With other Science Gleanings, Two Essays on Whist, and Correspondence with Sir John Herschel. With 9 Star-Maps and Diagrams. Crown 8vo. 6*s*.

Half-Hours with the Telescope: a Popular Guide to the Use of the Telescope as a means of Amusement and Instruction. With 7 Plates. Fcp. 8vo. 2*s*. 6*d*.

The Southern Skies: a Plain and Easy Guide to the Constellations of the Southern Hemisphere. Showing in 12 Maps the position of the principal Star-Groups night after night throughout the year. With an Introduction and a separate Explanation of each Map. True for every Year. 4to. 5*s*.

Half-Hours with the Stars: a Plain and Easy Guide to the Knowledge of the Constellations. Showing in 12 Maps the position of the principal Star-Groups night after night throughout the Year. With Introduction and a separate Explanation of each Map. True for every Year. 4to. 3*s*. 6*d*.

New Star Atlas for the Library, the School, and the Observatory, in Twelve Circular Maps (with 2 Index-Plates). With an Introduction on the Study of the Stars, Illustrated by 9 Diagrams. Crown 8vo. 5*s*.

Larger Star Atlas for Observers and Students. In Twelve Circular Maps, showing 6000 Stars, 1500 Double Stars, Nebulæ, &c. With 2 Index-Plates. Folio, 15*s*.

The Stars in their Seasons: an Easy Guide to a Knowledge of the Star Groups. In 12 Large Maps. Imperial 8vo. 5*s*.

The Star Primer: showing the Starry Sky, Week by Week. In 24 Hourly Maps. Crown 4to. 2*s*. 6*d*.

Chance and Luck: a Discussion of the Laws of Luck, Coincidence, Wagers, Lotteries, and the Fallacies of Gambling, &c. Crown 8vo. 3*s*. boards. 2*s*. 6*d*. cloth.

Rough Ways made Smooth. Familiar Essays on Scientific Subjects. Crown 8vo. 3*s*. 6*d*.

Pleasant Ways in Science. Crown 8vo. 5*s*. Cheap Edition. Crown 8vo. 3*s*. 6*d*.

The Great Pyramid, Observatory, Tomb, and Temple. With Illustrations. Crown 8vo. 5*s*.

Nature Studies. By R. A. Proctor, Grant Allen, A. Wilson, T. Foster and E. Clodd. Cr. 8vo. 5*s*. Cheap Edition. Cr. 8vo. 3*s*. 6*d*.

Leisure Readings. By R. A. Proctor, E. Clodd, A. Wilson, T. Foster and A. C. Ranyard. Cr. 8vo. 3*s*. 6*d*.

Lessons in Elementary Astronomy; with Hints for Young Telescopists. With 47 Woodcuts. Fcp. 8vo. 1*s*. 6*d*.

MANUFACTURES, TECHNOLOGY, &c.

BELL—Jacquard Weaving and Designing. By F. T. BELL, National Scholar in Design (1875-8) and Third Grade Certificated Art Master, Science and Art Department, S.K.; Medallist in Honours and Certificated Teacher in 'Linen Manufacturing' and in 'Weaving and Pattern Designing,' City and Guilds of London Institute. With 199 Diagrams. 8vo. 12*s.* net.

LUPTON—Mining: an Elementary Treatise on the Getting of Minerals. By ARNOLD LUPTON, M.I.C.E., F.G.S., &c., Mining Engineer, Certificated Colliery Manager, Surveyor, &c. Professor of Coal Mining at the Victoria University, Yorkshire College, Leeds, &c. With 596 Diagrams and Illustrations. Crown 8vo. 9*s.* net.

TAYLOR—Cotton Weaving and Designing. By JOHN T. TAYLOR, Lecturer on Cotton Weaving and Designing in the Preston, Ashton-under-Lyne, Chorley, and Todmorden Technical Schools, &c. With 373 Diagrams. Crown 8vo. 7*s.* 6*d.* net.

WATTS—An Introductory Manual for Sugar Growers. By FRANCIS WATTS, F.C.S., F.I.C., Assoc. Mason Coll., Birmingham, and Government Chemist, Antigua, West Indies. With 20 Illustrations. Crown 8vo. 6*s.*

PHYSIOGRAPHY AND GEOLOGY.

BIRD—Works by CHARLES BIRD, B.A., F.G.S., Head-master of the Rochester Mathematical School.

—— **Elementary Geology.** With Geological Map of the British Isles, and 247 Illustrations. Crown 8vo. 2*s.* 6*d.*

—— **Geology:** a Manual for Students in Advanced Classes and for General Readers. With over 300 Illustrations, a Geological Map of the British Isles (coloured), and a set of Questions for Examination. Crown 8vo. 7*s.* 6*d.*

GREEN—Physical Geology for Students and General Readers. With Illustrations. By A. H. GREEN, M.A., F.G.S., Professor of Geology in the University of Oxford. 8vo. 21*s.*

LEWIS—Papers and Notes on the Glacial Geology of Great Britain and Ireland. By the late HENRY CARVILL LEWIS, M.A., F.G.S., Professor of Mineralogy in the Academy of Natural Sciences, Philadelphia, and Professor of Geology in Haverford College, U.S.A. Edited from his unpublished MSS. With an Introduction by HENRY W. CROSSKEY, LL.D., F.G.S. With 10 Maps and 82 Illustrations and Diagrams. 8vo. 21*s.*

THORNTON—Works by JOHN THORNTON, M.A.

—— **Elementary Physiography:** an Introduction to the Study of Nature. With 12 Maps and 247 Illustrations. With Appendix on Astronomical Instruments and Measurements. Crown 8vo. 2*s*. 6*d*.

—— **Advanced Physiography.** With 6 Maps and 180 Illustrations Crown 8vo. 4*s*. 6*d*.

TYNDALL—**The Glaciers of the Alps:** being a Narrative of Excursions and Ascents. An Account of the Origin and Phenomena of Glaciers, and an Exposition of the Physical Principles to which they are related. By JOHN TYNDALL, F.R.S. With 61 Illustrations. Crown 8vo. 6*s*. 6*d*. net.

HEALTH AND HYGIENE.

BRODRIBB—**Manual of Health and Temperance.** By T. BRODRIBB, M.A. With Extracts from Gough's 'Temperance Orations'. Revised and Edited by the Rev. W. RUTHVEN PYM, M.A. Crown 8vo. 1*s*. 6*d*.

BUCKTON—**Health in the House;** Twenty-five Lectures on Elementary Physiology in its Application to the Daily Wants of Man and Animals. By CATHERINE M. BUCKTON. With 41 Woodcuts and Diagrams. Crown 8vo. 2*s*.

CORFIELD—**The Laws of Health.** By W. H. CORFIELD, M.A., M.D. Fcp. 8vo. 1*s*. 6*d*.

FRANKLAND—**Micro-Organisms in Water,** their Significance, Identification, and Removal. Together with an Account of the Bacteriological Methods involved in their Investigation. Specially Designed for those connected with the Sanitary Aspects of Water Supply. By Professor PERCY FRANKLAND, Ph.D., B.Sc. (Lond.), F.R.S., and Mrs. PERCY FRANKLAND. 8vo. 16*s*. net.

NOTTER—**Hygiene.** By J. LANE NOTTER, M.A., M.D. (Dublin), Fellow and Member of Council of the Sanitary Institute of Great Britain, Examiner in Hygiene, Science and Art Department, Examiner in Public Health in the University of Cambridge and in the Victoria University, Manchester, &c.; and R. H. FIRTH, F.R.C.S., Assistant Professor of Hygiene in the Army Medical School, Netley, &c. With 95 Illustrations. Crown 8vo. 3*s*. 6*d*.

POORE—**Essays on Rural Hygiene.** By GEORGE VIVIAN POORE, M.D Crown 8vo. 6*s*. 6*d*.

WILSON—**A Manual of Health-Science:** adapted for use in Schools and Colleges, and suited to the Requirements of Students preparing for the Examinations in Hygiene of the Science and Art Department, &c. By ANDREW WILSON, F.R.S.E., F.L.S., &c. With 74 Illustrations Crown 8vo. 2*s*. 6*d*.

OPTICS AND PHOTOGRAPHY.

ABNEY—A Treatise on Photography. By Captain W. DE WIVELESLIE ABNEY, F.R.S., Director for Science in the Science and Art Department. With 115 Woodcuts. Fcp. 8vo. 3*s*. 6*d*.

GLAZEBROOK—Physical Optics. By R. T. GLAZEBROOK, M.A., F.R.S., Fellow and Lecturer of Trin. Coll., Demonstrator of Physics at the Cavendish Laboratory, Cambridge. With 183 Woodcuts of Apparatus, &c. Fcp. 8vo. 6*s*.

WRIGHT—Optical Projection: a Treatise on the Use of the Lantern in Exhibition and Scientific Demonstration. By LEWIS WRIGHT, Author of 'Light: a Course of Experimental Optics'. With 232 Illustrations. Crown 8vo. 6*s*.

PHYSIOLOGY, BIOLOGY, &c.

ASHBY—Notes on Physiology for the Use of Students preparing for Examination. By HENRY ASHBY, M.D. With 141 Illustrations. Fcp. 8vo. 5*s*.

BARNETT—The Making of the Body: a Children's Book on Anatomy and Physiology, for School and Home Use. By Mrs. S. A. BARNETT, Author of 'The Making of the Home'. With 113 Illustrations. Crown 8vo. 1*s*. 9*d*.

BIDGOOD—A Course of Practical Elementary Biology. By JOHN BIDGOOD, B.Sc., F.L.S. With 226 Illustrations. Crown 8vo. 4*s*. 6*d*.

BRAY—Physiology and the Laws of Health, in Easy Lessons for Schools. By Mrs. CHARLES BRAY. Fcp. 8vo. 1*s*.

FURNEAUX—Human Physiology. By W. FURNEAUX, F.R.G.S. With 218 Illustrations. Crown 8vo. 2*s*. 6*d*.

HUDSON and GOSSE—The Rotifera, or 'Wheel-Animalcules'. By C. T. HUDSON, LL.D., and P. H. GOSSE, F.R.S. With 30 Coloured and 4 Uncoloured Plates. In 6 Parts. 4to. 10*s*. 6*d*. each; Supplement, 12*s*. 6*d*. Complete in 2 vols. with Supplement, 4to. £4 4*s*.

MACALISTER—Works by ALEXANDER MACALISTER, M.D., Professor of Anatomy, University of Cambridge.

—— **Zoology and Morphology of Vertebrata.** 8vo. 10*s*. 6*d*.

—— **Zoology of the Invertebrate Animals.** With 59 Diagrams. Fcp. 8vo. 1*s*. 6*d*.

—— **Zoology of the Vertebrate Animals.** With 77 Diagrams. Fcp. 8vo. 1*s*. 6*d*.

MORGAN—Animal Biology: an Elementary Text-Book. By C. LLOYD MORGAN, Professor of Animal Biology and Geology in University College, Bristol. With numerous Illustrations. Cr. 8vo. 8*s*. 6*d*.

THORNTON—Human Physiology. By JOHN THORNTON, M.A. With 267 Illustrations, some of which are coloured. Crown 8vo. 6*s*.

BOTANY.

AITKEN—Elementary Text-Book of Botany. For the use of Schools. By EDITH AITKEN, late Scholar of Girton College. With over 400 Diagrams. Crown 8vo. 4*s*. 6*d*.

BENNETT and MURRAY—Handbook of Cryptogamic Botany. By ALFRED W. BENNETT, M.A., B.Sc., F.L.S., Lecturer on Botany at St. Thomas's Hospital; and GEORGE MURRAY, F.L.S., Keeper of Botany, British Museum. With 378 Illustrations. 8vo. 16*s*.

CROSS and BEVAN—Cellulose: an Outline of the Chemistry of the Structural Elements of Plants. With Reference to their Natural History and Industrial Uses. By CROSS AND BEVAN (C. F. CROSS E. J. BEVAN, and C. BEADLE). With 14 Plates. Crown 8vo. 12*s*. net.

EDMONDS—Elementary Botany. Theoretical and Practical. By HENRY EDMONDS, B.Sc., London. With 319 Diagrams and Woodcuts. Crown 8vo. 2*s*. 6*d*.

KITCHENER—A Year's Botany. Adapted to Home and School Use. With Illustrations by the Author. By FRANCES ANNA KITCHENER. Crown 8vo. 5*s*.

LINDLEY and MOORE—The Treasury of Botany: or, Popular Dictionary of the Vegetable Kingdom: with which is incorporated a Glossary of Botanical Terms. Edited by J. LINDLEY, M.D., F.R.S., and T. MOORE, F.L.S. With 20 Steel Plates and numerous Woodcuts. 2 Parts. Fcp. 8vo. 12*s*.

McNAB—Class-Book of Botany. By W. R. McNAB. 2 Parts. Morphology and Physiology. With 42 Diagrams. Fcp. 8vo. 1*s*. 6*d*. Classification of Plants. With 118 Diagrams. Fcp. 8vo. 1*s*. 6*d*.

THOMÉ and BENNETT—Structural and Physiological Botany. By Dr. OTTO WILHELM THOMÉ and by ALFRED W. BENNETT, M.A., B.Sc., F.L.S. With Coloured Map and 600 Woodcuts. Fcp. 8vo. 6*s*.

TUBEUF—Diseases of Plants Due to Cryptogamic Parasites. Translated from the German of Dr. CARL FREIHERR von TUBEUF, of the University of Munich, by WILLIAM G. SMITH, B.Sc., Ph.D., Lecturer on Plant Physiology to the University of Edinburgh. With over 300 Illustrations. [*In preparation.*

WATTS—A School Flora. For the use of Elementary Botanical Classes. By W. MARSHALL WATTS, D.Sc., Lond. Cr. 8vo. 2*s*. 6*d*.

AGRICULTURE AND GARDENING.

ADDYMAN—Agricultural Analysis. A Manual of Quantitative Analysis for Students of Agriculture. By FRANK T. ADDYMAN, B.Sc. (Lond.), F.I.C. With 49 Illustrations. Crown 8vo. 5*s*. net.

COLEMAN and ADDYMAN—Practical Agricultural Chemistry. For Elementary Students, adapted for use in Agricultural Classes and Colleges. By J. BERNARD COLEMAN, A.R.C.Sc., F.I.C., and FRANK T. ADDYMAN, B.Sc. (Lond.), F.I.C. Crown 8vo. 1*s*. 6*d*. net.

LOUDON—Works by J. C. LOUDON, F.L.S.

—— **Encyclopædia of Gardening;** the Theory and Practice of Horticulture, Floriculture, Arboriculture and Landscape Gardening. With 1000 Woodcuts. 8vo. 21*s*.

—— **Encyclopædia of Agriculture;** the Laying-out, Improvement and Management of Landed Property; the Cultivation and Economy of the Productions of Agriculture. With 1100 Woodcuts. 8vo. 21*s*.

RIVERS—The Miniature Fruit Garden; or, The Culture of Pyramidal and Bush Fruit Trees. By THOMAS T. F. RIVERS. With 32 Illustrations. Crown 8vo. 4*s*.

SORAUER—A Popular Treatise on the Physiology of Plants. For the Use of Gardeners, or for Students of Horticulture and of Agriculture. By Dr. PAUL SORAUER, Director of the Experimental Station at the Royal Pomological Institute in Proskau (Silesia). Translated by F. E. WEISS, B.Sc., F.L.S., Professor of Botany at the Owens College, Manchester. With 33 Illustrations. 8vo. 9*s*. net.

WEBB—Works by HENRY J. WEBB, Ph.D., B.Sc. (Lond.); late Principal of the Agricultural College, Aspatria.

—— **Elementary Agriculture.** A Text-Book specially adapted to the requirements of the Science and Art Department, the Junior Examination of the Royal Agricultural Society and other Elementary Examinations. With 34 Illustrations. Crown 8vo. 2*s*. 6*d*.

—— **Advanced Agriculture.** With 100 Illustrations and a set of Questions for Examination. Crown 8vo. 7*s*. 6*d*. net.

TEXT-BOOKS OF SCIENCE.

(Adapted for the Use of Students in Public or Science Schools.)

Photography. By Captain W. DE WIVELESLIE ABNEY, C.B., F.R.S., 105 Woodcuts. Fcp. 8vo. 3*s.* 6*d.*

The Strength of Material and Structures. By Sir J. ANDERSON, C.E., &c. 66 Woodcuts. Fcp. 8vo. 3*s.* 6*d.*

Railway Appliances—A Description of Details of Railway Construction subsequent to the completion of Earthworks and Structures. By JOHN WOLFE BARRY, C.B., M.I.C.E. 218 Woodcuts. Fcp. 8vo. 4*s.* 6*d.*

Introduction to the Study of Inorganic Chemistry. By WILLIAM ALLEN MILLER, M.D., F.R.S. 72 Woodcuts. 3*s.* 6*d.*

Quantitative Chemical Analysis. By T. E. THORPE, F.R.S., Ph.D. With 88 Woodcuts. Fcp. 8vo. 4*s.* 6*d.*

Qualitative Chemical Analysis and Laboratory Practice. By T. E. THORPE, Ph.D., F.R.S., and M. M. PATTISON MUIR, M.A. With Plate of Spectra and 57 Woodcuts. Fcp. 8vo. 3*s.* 6*d.*

Introduction to the Study of Chemical Philosophy. By WILLIAM A. TILDEN, D.Sc., London, F.R.S. With 5 Woodcuts. With or without Answers to Problems. Fcp. 8vo. 4*s.* 6*d.*

Elements of Astronomy. By Sir R. S. BALL, LL.D., F.R.S. With 136 Woodcuts. Fcp. 8vo. 6*s.*

Systematic Mineralogy. By HILARY BAUERMAN, F.G.S. With 373 Woodcuts. Fcp. 8vo. 6*s.*

Descriptive Mineralogy. By HILARY BAUERMAN, F.G.S., &c. With 236 Woodcuts. Fcp. 8vo. 6*s.*

Metals, their Properties and Treatment. By C. L. BLOXAM, and A. K. HUNTINGTON, Professors in King's College, London. 130 Woodcuts. Fcp. 8vo. 5*s.*

Theory of Heat. By J. CLERK MAXWELL M.A., LL.D., Edin., F.R.SS., L. and E. With 38 Illustrations. Fcp. 8vo. 4*s.* 6*d.*

Practical Physics. By R. T. GLAZEBROOK M.A., F.R.S., and W. N. SHAW, M.A. With 134 Woodcuts. Fcp. 8vo. 7*s.* 6*d.*

Preliminary Survey. Including Elementary Astronomy, Route Surveying, &c. By THEODORE GRAHAM GRIBBLE, Civil Engineer. 130 Illustrations. Fcp. 8vo. 6*s.*

Algebra and Trigonometry. By WILLIAM NATHANIEL GRIFFIN, B.D. 3*s.* 6*d.* Notes on, with Solutions of the more difficult Questions. Fcp. 8vo. 3*s.* 6*d.*

The Steam Engine. By GEORGE C. V. HOLMES. 212 Woodcuts. Fcp. 8vo. 6*s.*

Electricity and Magnetism. By FLEEMING JENKIN, F.R.SS., L. and E. With 177 Woodcuts. Fcp. 8vo. 3*s.* 6*d.*

The Art of Electro-Metallurgy, including all known Processes of Electro-Deposition. By G. GORE, LL.D., F.R.S. With 56 Woodcuts. Fcp. 8vo. 6*s.*

Telegraphy. By W. H. PREECE, C.B. F.R.S., V.P. Inst. C.E., and Sir J. SIVEWRIGHT, M.A., K.C.M.G. 258 Woodcuts. Fcp. 8vo. 6*s.*

Physical Optics. By R. T. GLAZEBROOK, M.A., F.R.S. With 183 Woodcuts. Fcp. 8vo. 6*s.*

Technical Arithmetic and Mensuration. By CHARLES W. MERRIFIELD, F.R.S. 3*s.* 6*d.* Key, 3*s.* 6*d.*

The Study of Rocks, an Elementary Text-Book of Petrology. By FRANK RUTLEY, F.G.S. With 6 Plates and 88 Woodcuts. Fcp. 8vo. 4*s.* 6*d.*

Workshop Appliances, including Descriptions of some of the Gauging and Measuring Instruments—Hand-Cutting Tools, Lathes, Drilling, Planing, and other Machine Tools used by Engineers. By C. P. B. SHELLEY, M.I.C.E. With 323 Woodcuts. Fcp. 8vo. 5*s.*

Elements of Machine Design. By W. CAWTHORNE UNWIN, F.R.S., B.Sc.

Part I. General Principles, Fastenings, and Transmissive Machinery. 304 Woodcuts. 6*s.*

Part II. Chiefly on Engine Details. 174 Woodcuts. Fcp. 8vo. 4*s.* 6*d.*

Structural and Physiological Botany. By Dr. OTTO WILHELM THOMÉ, and A. W. BENNETT, M.A., B.Sc., F.L.S. With 600 Woodcuts. Fcp. 8vo. 6*s.*

Plane and Solid Geometry. By H. W. WATSON, M.A. Fcp. 8vo. 3*s.* 6*d.*

ELEMENTARY SCIENCE MANUALS.

Written specially to meet the requirements of the ELEMENTARY STAGE OF SCIENCE SUBJECTS *as laid down in the Syllabus of the Directory of the* SCIENCE AND ART DEPARTMENT.

Practical Plane and Solid Geometry, including Graphic Arithmetic. By I. H. MORRIS. Cr. 8vo. 2*s.* 6*d.*

Geometrical Drawing for Art Students. Embracing Plane Geometry and its Applications, the use of Scales, and the Plane and Elevations of Solids, as required in Section I. of Science Subject I. By I. H. MORRIS. Crown 8vo. 1*s.* 6*d.*
Being the First Part of Morris's Practical Plane and Solid Geometry.

Text-Book on Practical, Solid, or Descriptive Geometry. By DAVID ALLEN LOW. Part I. Crown 8vo. 2*s.* Part II. Crown 8vo. 3*s.*

An Introduction to Machine Drawing and Design. By DAVID ALLEN LOW. With 97 Illustrations Cr. 8vo. 2*s.*

Building Construction. By EDWARD J. BURRELL. With 308 Illustrations. Crown 8vo. 2*s.* 6*d.*

An Elementary Course of Mathematics. Containing Arithmetic; Euclid (Book I. with Deductions and Exercises); and Algebra. Crown 8vo. 2*s.* 6*d.*

Theoretical Mechanics. Including Hydrostatics and Pneumatics. By J. E. TAYLOR, M.A., B.Sc. With Examples and Answers, and 175 Diagrams and Illustrations. Cr. 8vo. 2*s.* 6*d.*

Theoretical Mechanics—Solids. By J. EDWARD TAYLOR, M.A., B.Sc. (Lond.). With 163 Illustrations, 120 Worked Examples, and over 500 Examples from Examination Papers, &c. Crown 8vo. 2*s.* 6*d.*

Theoretical Mechanics—Fluids. By J. EDWARD TAYLOR, M.A., B.Sc. (Lond.). With 122 Illustrations, numerous Worked Examples, and about 500 Examples from Examination Papers, &c. Crown 8vo. 2*s.* 6*d.*

A Manual of Mechanics: an Elementary Text-Book for Students of Applied Mechanics. With 138 Illustrations and Diagrams, and 188 Examples taken from the Science Department Examination Papers, with Answers. By T. M. GOODEVE. Fcp. 8vo. 2*s.* 6*d.*

Sound, Light, and Heat. By MARK R. WRIGHT. With 160 Diagrams and Illustrations. Crown 8vo. 2*s.* 6*d.*

Physics. Alternative Course. By MARK R. WRIGHT. With 242 Illustrations. Crown 8vo. 2*s.* 6*d.*

Magnetism and Electricity. By A. W. POYSER, M.A. With 235 Illustrations. Crown 8vo. 2*s.* 6*d.*

Problems and Solutions in Elementary Electricity and Magnetism. Embracing a Complete Set of Answers to the South Kensington Papers for the Years 1885-1894, and a Series of Original Questions. By W. SLINGO and A. BROOKER. With 67 Illustrations. Crown 8vo. 2*s.*

Inorganic Chemistry, Theoretical and Practical. By WILLIAM JAGO, F.C.S., F.I.C. With 63 Woodcuts and Questions and Exercises. Fcp. 8vo. 2*s.* 6*d.*

An Introduction to Practical Inorganic Chemistry. By WILLIAM JAGO, F.C.S., F.I.C. Crown 8vo. 1*s.* 6*d.*

Practical Chemistry: the Principles of Qualitative Analysis. By WILLIAM A. TILDEN, D.Sc. Fcp. 8vo. 1*s.* 6*d.*

Elementary Chemistry, Inorganic and Organic. By W. S. FURNEAUX, F.R.G.S. With 65 Illustrations. Cr. 8vo. 2*s.* 6*d.*

Organic Chemistry: The Fatty Compounds. By R. LLOYD WHITELEY, F.I.C., F.C.S., With 45 Illustrations. Crown 8vo. 3*s.* 6*d.*

Elementary Geology. By CHARLES BIRD, B.A., F.G.S. With 247 Illustrations. Crown 8vo. 2*s.* 6*d.*

Human Physiology. By WILLIAM S. FURNEAUX, F.R.G.S. With 218 Illustrations. Crown 8vo. 2*s.* 6*d.*

Hygiene. By J. LANE NOTTER, M.A., M.D. (Dublin), and R. H. FIRTH, F.R.C.S. With 95 Illustrations. Crown 8vo. 3*s.* 6*d.*

Elementary Botany, Theoretical and Practical. By HENRY EDMONDS, B.Sc., London. 319 Illustrations. Crown 8vo. 2*s.* 6*d.*

Metallurgy. By E. L. RHEAD. With 94 Illustrations. Cr. 8vo. 3*s.* 6*d.*

[*Continued*.

ELEMENTARY SCIENCE MANUALS—*Continued.*

Steam. By WILLIAM RIPPER, Member of the Institution of Mechanical Engineers. With 142 Illustrations. Crown 8vo. 2*s.* 6*d.*

Elementary Physiography. By J. THORNTON, M.A. With 12 Maps and 247 Illustrations. With Appendix on Astronomical Instruments and Measurements. Crown 8vo. 2*s.* 6*d.*

Agriculture. By HENRY J. WEBB, Ph.D., late Principal of the Agricultural College, Aspatria. With 34 Illustrations. Crown 8vo. 2*s.* 6*d.*

A Course of Practical Elementary Biology. By J. BIDGOOD, B.Sc. With 226 Illustrations. Crown 8vo. 4*s.* 6*d.*

ADVANCED SCIENCE MANUALS.

Written specially to meet the requirements of the ADVANCED STAGE OF SCIENCE SUBJECTS *as laid down in the Syllabus of the Directory of the* SCIENCE AND ART DEPARTMENT.

Agriculture. By HENRY J. WEBB, Ph.D., late Principal of the Agricultural College, Aspatria. With 100 Illustrations. Crown 8vo. 7*s.* 6*d.* net.

Magnetism and Electricity. By ARTHUR WILLIAM POYSER, M.A., Trinity College, Dublin. With 317 Diagrams. Crown 8vo. 4*s.* 6*d.*

Inorganic Chemistry, Theoretical and Practical. A Manual for Students in Advanced Classes of the Science and Art Department. By WILLIAM JAGO, F.C.S., F.I.C. With Plate of Spectra, and 78 Woodcuts. Crown 8vo. 4*s.* 6*d.*

Physiography. By JOHN THORNTON, M.A. With 6 Maps, 180 Illustrations, and Plate of Spectra. Cr. 8vo. 4*s.* 6*d.*

Heat. By MARK R. WRIGHT, Hon. Inter. B.Sc., (Lond.). With 136 Illustrations and numerous Examples and Examination Papers. Cr. 8vo. 4*s.* 6*d.*

Building Construction. By the Author of 'Rivington's Notes on Building Construction'. With 385 Illustrations, and an Appendix of Examination Questions. Crown 8vo. 4*s.* 6*d.*

Human Physiology. By JOHN THORNTON, M.A. With 258 Illustrations, some of which are coloured. Crown 8vo. 6*s.*

Theoretical Mechanics—Solids. Including Kinematics, Statics, and Kinetics. By ARTHUR THORNTON, M.A., F.R.A.S. With 220 Illustrations, 130 Worked Examples, and over 900 Examples from Examination Papers, &c. Crown 8vo. 4*s.* 6*d.*

THE LONDON SCIENCE CLASS-BOOKS.

Edited by G. CAREY FOSTER, F.R.S., and by Sir PHILIP MAGNUS, B.Sc., B.A., of the City and Guilds of London Institute.

Astronomy. By Sir ROBERT STAWELL BALL, LL.D., F.R.S. With 41 Diagrams. 1*s.* 6*d.*

Mechanics. By Sir ROBERT STAWELL BALL, LL.D., F.R.S. With 89 Diagrams. 1*s.* 6*d.*

The Laws of Health. By W. H. CORFIELD, M.A., M.D., F.R.C.P. With 22 Illustrations. 1*s.* 6*d.*

Molecular Physics and Sound. By FREDERICK GUTHRIE, F.R.S. With 91 Diagrams. 1*s.* 6*d.*

Geometry, Congruent Figures. By O. HENRICI, Ph.D., F.R.S. With 141 Diagrams. 1*s.* 6*d.*

Zoology of the Invertebrate Animals. By ALEXANDER MACALISTER, M.D. With 59 Diagrams. 1*s.* 6*d.*

Zoology of the Vertebrate Animals. By ALEXANDER MACALISTER, M.D. With 77 Diagrams. 1*s.* 6*d.*

Hydrostatics and Pneumatics. By Sir PHILIP MAGNUS, B.Sc., B.A. With 79 Diagrams. 1*s.* 6*d.* (To be had also *with Answers*, 2*s.*) The Worked Solution of the Problems. 2*s.*

Botany. Outlines of the Classification of Plants. By W. R. MCNAB, M.D. With 118 Diagrams. 1*s.* 6*d.*

Botany. Outlines of Morphology and Physiology. By W. R. MCNAB, M.D. With 42 Diagrams. 1*s.* 6*d.*

Thermodynamics. By RICHARD WORMELL, M.A., D.Sc. With 41 Diagrams. 1*s.* 6*d.*

(5000—4/96.)

HARVARD ENGINEERING SCHOOL